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SPECTRAL ANALYSIS OF SUDBURY BASIN SEISMIC DATA FOR THE PROPOSED NEUTRINO LABORATORY SITE IN THE CREIGHTON MINE, SUDBURY, ONTARIO

L. Laverdure and P. Rochon

DIVISION REPORT MRL 91-131(TR) NOVEMBER 1991

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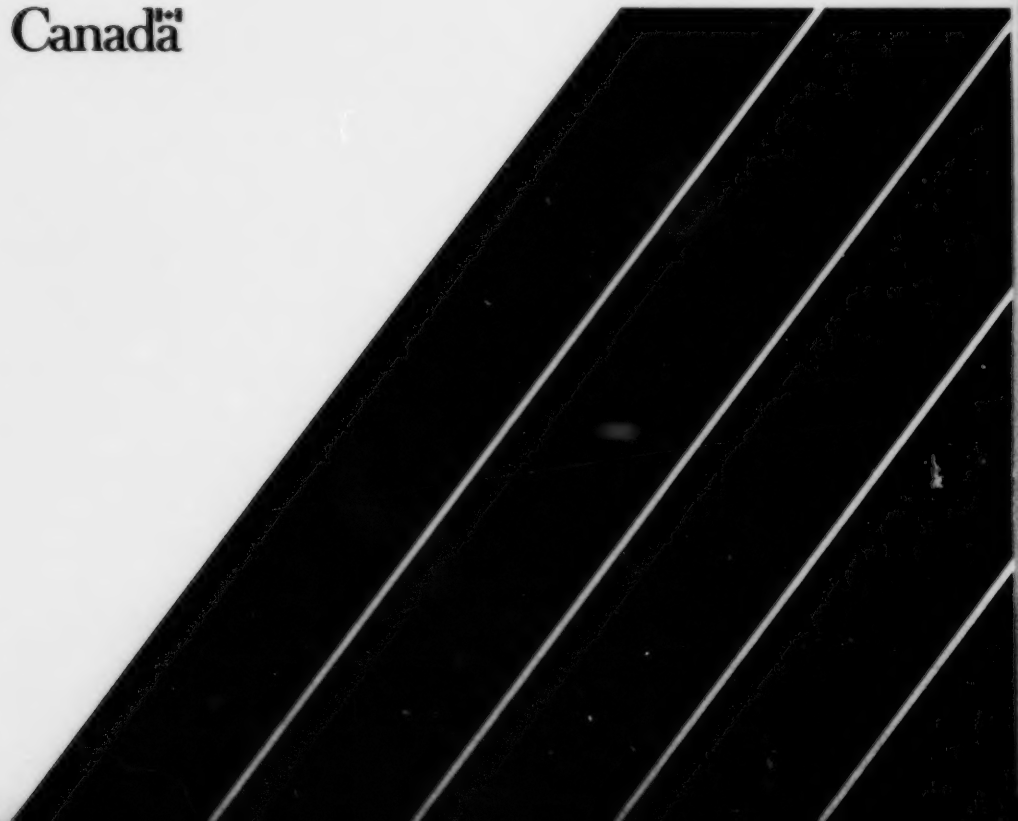

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L. Laverdure* and P. Rochon**

ABSTRACT

Design of an underground laboratory requires knowledge of shear wave (S-wave) acceleration values in the frequency domain. CANMET records the full waveforms of mining induced seismic events and earthquakes in the Sudbury Basin. Fifteen events of magnitude 2.0 Mn or greater were analyzed. Source-receiver distances for these events vary from 87 to 2130 meters. This report deals with spectral analysis of ground acceleration and graphs of acceleration/frequency (frequency domain) are plotted. The record of acceleration for frequencies below 30 Hz is provided on an accompanying DOS disc containing 53 ASCII files.

Key words: Acceleration; Frequency domain; Sudbury Basin.

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ANALYSE SPECTRALE DE DONNEES SEISMIQUES DANS LE BASSIN DE SUDBURY POUR LE FUTUR LABORATOIRE DE NEUTRINO A LA MINE CREIGHTON, SUDBURY, ONTARIO

L. Laverdure* et P. Rochon**

RESUME

Pour effectuer le design d'un laboratoire souterrain les données de l'accélération du sol, dans le domaine des fréquences, sont essentielles. CANMET enregistre les ondes séismiques produites lors des coups de toit et des tremblements de terre dans le Bassin de Sudbury. Quinze événements de magnitude 2.0 Mn ou plus ont été analysés. Les distances source-récepteurs varient entre 87 et 2130 mètres. Le rapport est accompagné par une disquette DOS de 53 fichiers ASCII contenant les valeurs de l'accélération pour les fréquences inférieures à 30 Hz.

Mot clés: Accélération; Domaine des fréquences; Bassin de Sudbury.

*Chercheure Scientifique, **Ingénieur en contrôle des sols, Laboratoire d'Elliot Lake, CANMET, Energie, Mines et Ressources Canada, Elliot Lake, Ontario.

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INTRODUCTION

The goal of this study is to calculate the acceleration values of seismic events, in the frequency domain, collected by the CANMET Macroseismic System, in order to establish a data bank which will be used for the underground design of the Neutrino Laboratory located in the Creighton Mine in Sudbury. Fifteen mining induced seismic events of 2.0 Mn or more were studied. The distances between the seismic sources and receivers are from 87 to 2130 meters.

DATA COLLECTION

The full seismic waveforms of this study were collected by CANMET between 1988 and 1991 in the Sudbury Basin using the in-house manufactured hardware. CANMET uses two types of sensors (or geophones), velocity gauges and accelerometers. The accelerometer design is based on piezoelectric ceramics. The ceramic produces a voltage when it is compressed, i.e., when there is ground acceleration. All data were collected in the time domain. The only manipulation of the accelerometer records used to obtain the acceleration in the frequency domain was by the use of a Fast Fourier Transform (FFT) (1). The velocity gauge geophone design is based on a magnetic core surrounded by a coil. The relative movement between the coil and the core produces the signal. The velocity data were initially converted to acceleration (m/sec^2), and subsequently analyzed using FFT.

CANMET operates two types of seismographic stations. The first type comprises five triaxial geophones. With this arrangement, each seismic event was recorded at five different locations, depicted as site numbers one to five on the graphs accompanying this report (Figures 1.1.1 to 5.1.3). For each site the (x, y, z) coordinates correspond to east/west, north/south, and elevation), e.g., Figures 1.1.1 to 1.1.3. The second type of data was obtained from a portable seismograph consisting of one triaxial geophone.

With this unit each event consists of data collected at one site. Here again, the x, y, z graphs correspond to east, north and elevation (except for one event, Figure 3.3, for which x is north/south, y is east/west, and z is elevation).

The low-frequency filters are 0.01 Hz. Depending on the equipment, the high-frequency filters vary from 200 to 500 Hz. These filters are easily recognized on the graphs because the signal drastically diminishes at the corresponding high-frequency filter values.

DATA ANALYSIS

Since the data will be used for stability design, it was decided to provide only the acceleration data of the shear waves (S-waves) instead of the whole waveform as they contain the bulk of the energy dissipated, and thereafter are responsible for most of the damage associated with seismic deformation and earthquakes. In a first step, the full waveforms of each of fifteen events were examined and the S-wave windows were subsequently determined. The shear S-waves travel at a lower velocity than the compression P-waves. Following the liberation of seismic energy, the S-waves arrive at each geophone after the P-waves allowing the possibility of determining the shear window (2,3).

After switching the data from the time to the frequency domain using the one dimensional Fourier Transform, the acceleration in m/s^2 was plotted against frequency in Hz on a log-log scale. On the figures the vertical axis indices indicate the power of ten corresponding to the acceleration values. The total window indicates the number of points of the full waveform. The FFT window is related to the S-wave definition.

For source to receiver distances greater than 1,000 m, the plateau for the vertical z axis diagrams generally occurs at frequencies of 10 to 20 Hz for the low frequency corner, and 60 to 100 Hz for the high frequency corner.

For distances smaller than 1 km, the low frequency corner is generally between 20 to 50 Hz, and the high frequency corner is higher than 100 Hz, and often beyond the filter limitation. This is theoretically predictable since the earth is a low pass filter. The further the waves travel, the lower the frequency content attached to the waveform.

Moreover, the further the waves travel, the more damped they become, and thereafter, the shortest time span of the waveform is recorded (Table 1). This is true as long as the source mechanism is the same for each event as it is a function of the time taken for the release of energy by the source. It is also true that larger magnitudes correspond to longer window lengths. These trends are observed as long as the source-receiver distances are sufficient for the far field theory to be valid. When the source location is close to the geophones (e.g., on the order of less than 50 km in the case of earthquakes) the phenomena are not always easy to evaluate.

In other words, the frequency content and the window length are functions of:

- The event magnitude (the larger the event, the more energy released, which results in increased frequency content and window length).
- The travel path (the frequency content and the window length will be a function of the type of material the waves travel through: density, velocity, structure, water content, etc.).
- The source-receiver distance (the further the waves travel, the smaller the window length and the lower the frequency content).
- The damping factor of each material crossed (generally, the damping factors affect the higher frequencies more rapidly than the lower frequencies; the higher frequencies are thus attenuated faster).
- The source mechanism (the type of breakage mechanism which occurs when the seismic wave is emitted) i.e., fault slip, explosion, pillar burst, etc.

Table 1 - Magnitude, distance and window of the analyzed events.

Magnitude (Mn)	Distance (m)	Figure	NB. Points in Window
2.0	133	1.1	150
	416	1.2	423
	1088	1.3	767
	1171	1.4	426
	1303	1.5	359
2.4	168	2.1	292
	179	2.2	329
	381	2.3	411
	415	2.4	567
	1010	2.5	448
	1115	2.6	376
	1291	2.7	414
	1356	2.8	496
	1425	2.9	225
	2125	2.10	525
2.6	153	3.1	365
	410	3.2	362
	441	3.3	479
	1027	3.4	399
	1316	3.5	449
	1419	3.6	466
	1810	3.7	523

Cont.

Table 1 - cont.

Magnitude (Mn)	Distance (m)	Figure	NB. Points in Window
2.7	87	4.1	309
	134	4.2	129
	149	4.3	314
	168	4.4	399
	243	4.5	327
	254	4.6	346
	347	4.7	477
	381	4.8	388
	408	4.9	1101
	452	4.10	625
	465	4.11	329
	573	4.12	255
	959	4.13	273
	973	4.14	344
	1039	4.15	480
	1079	4.16	539
	1118	4.17	757
	1125	4.18	406
	1163	4.19	753
	1175	4.20	406
	1270	4.21	336
	1275	4.22	779
	1317	4.23	691
	1340	4.24	576
	1369	4.25	459
	1389	4.26	250
	1422	4.27	520
	1483	4.28	247
	1593	4.29	663
	2130	4.30	756
3.6	2090	5.1	713

DATA ON DISKETTE

At the request of Monenco, a DOS diskette containing the acceleration values for the frequencies below 30 Hz accompanies this report. Filenames correspond to figure numbers in the report; there are 53 files on the diskette. Appendix A provides an example of the data contained in one file.

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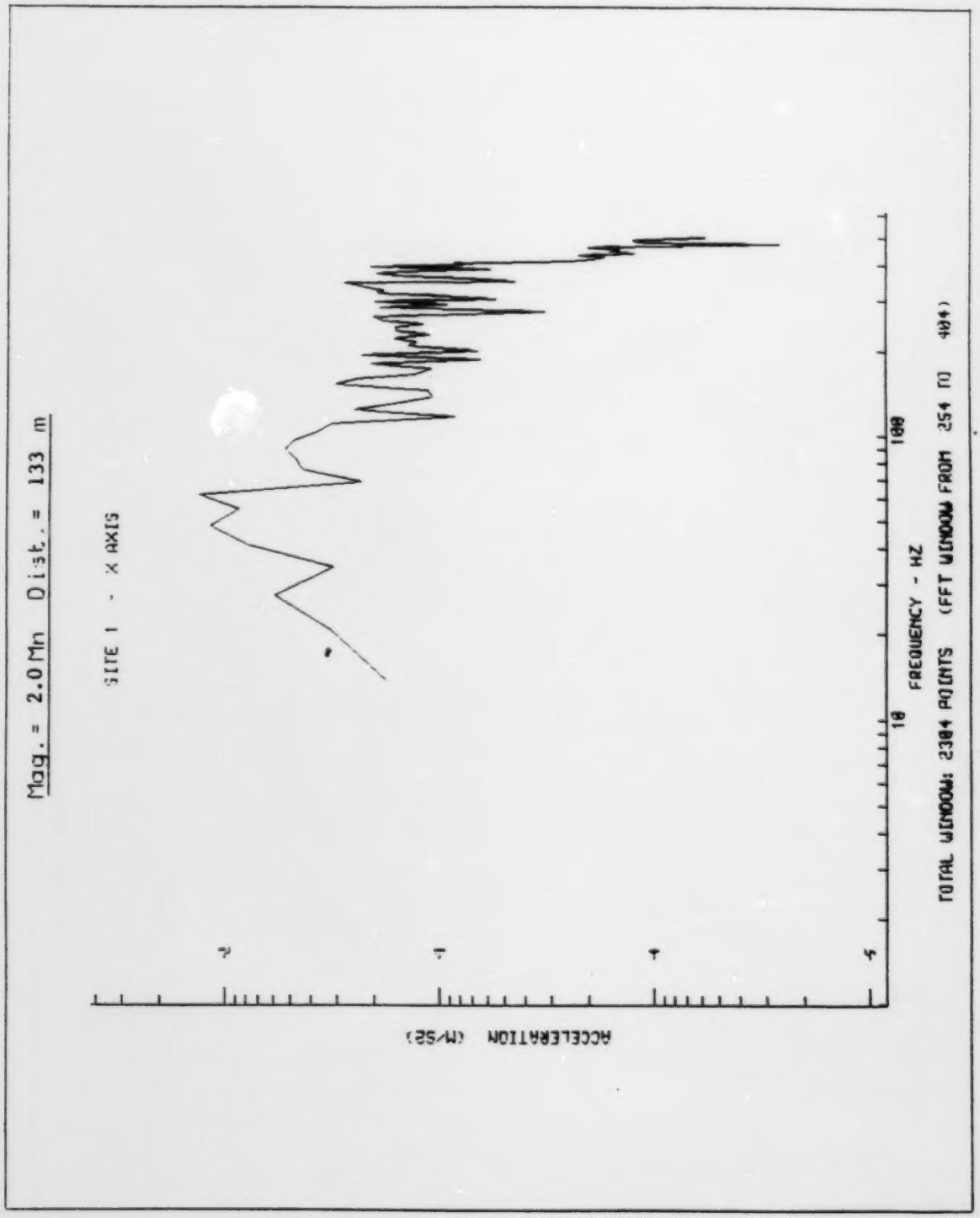


Fig. 1.1.1 - Log acceleration versus log frequency for east/west axis at 2.0 magnitude.

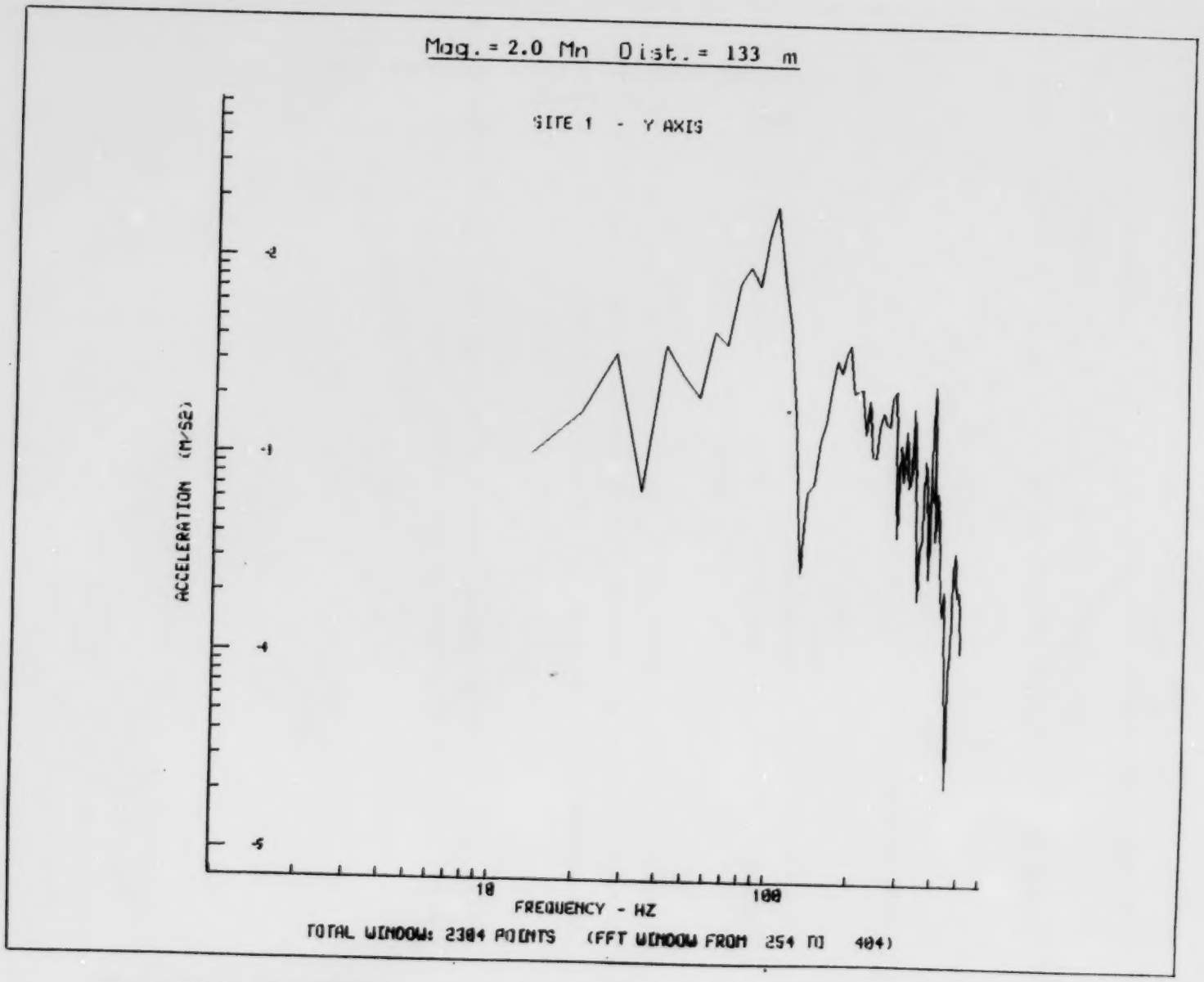


Fig. 1.1.2 - Log acceleration versus log frequency for north/south axis at 2.0 magnitude.

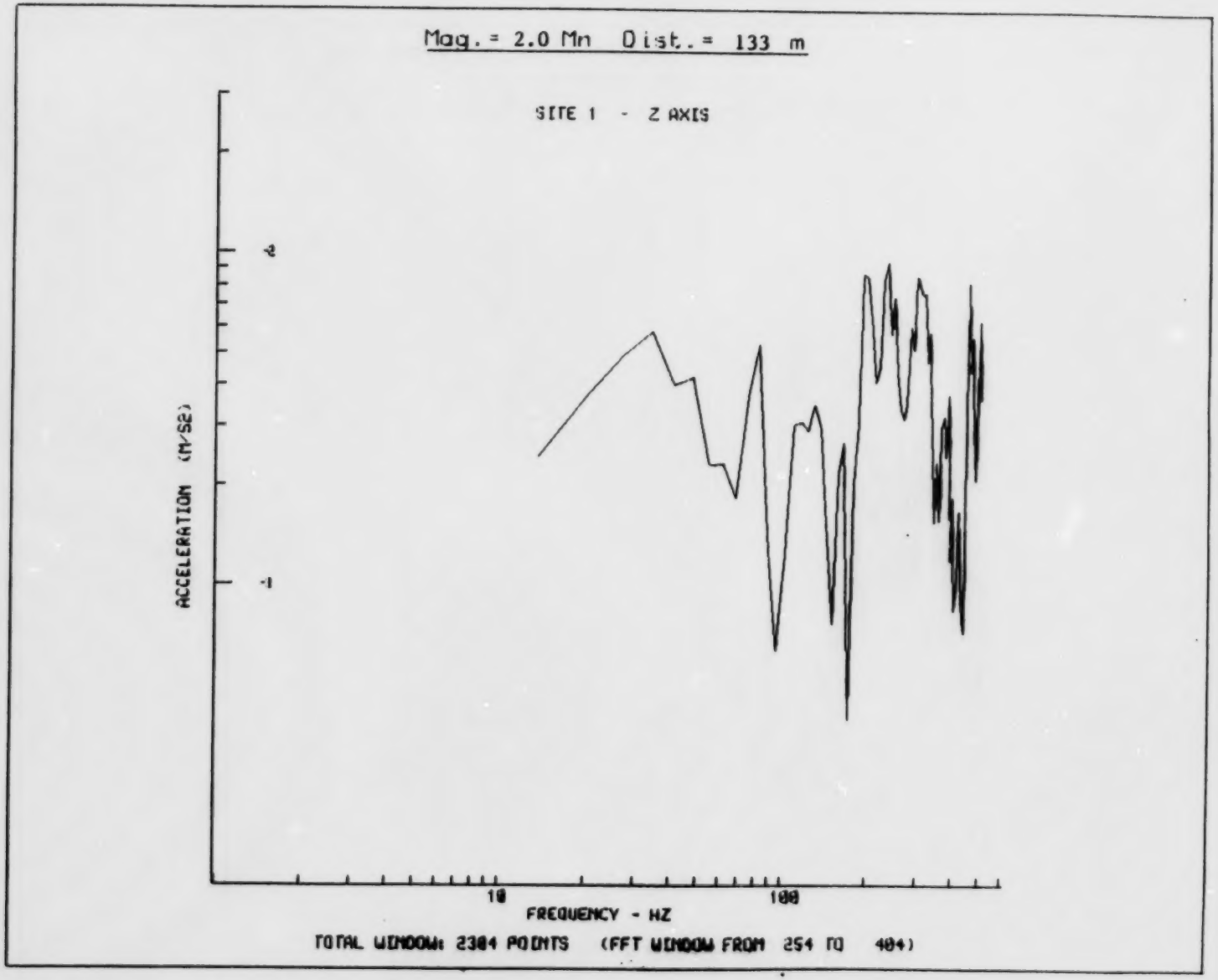


Fig. 1.1.3 - Log acceleration versus log frequency for elevation at 2.0 magnitude.

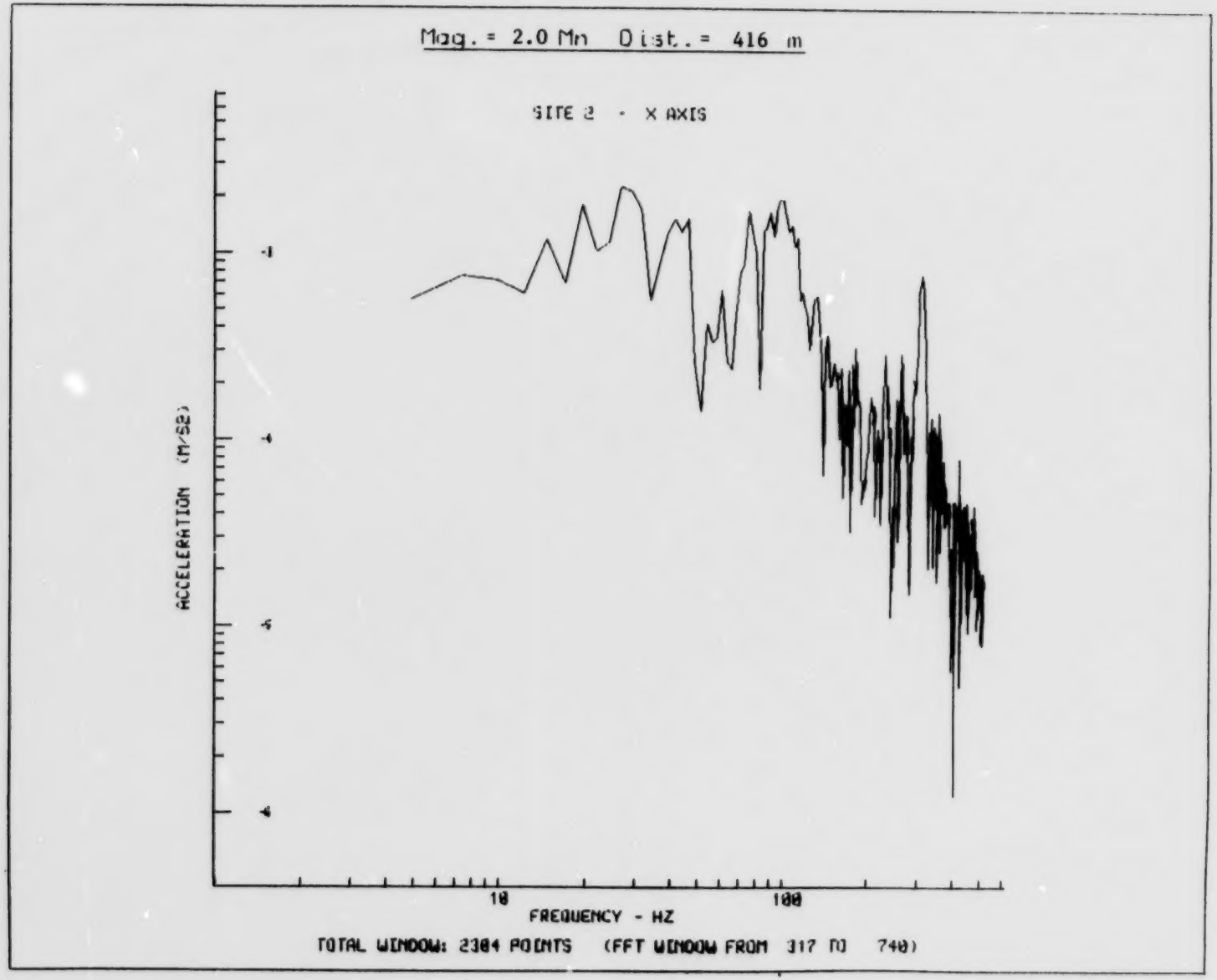


Fig. 1.2.1 - Log acceleration versus log frequency for east/west axis at 2.0 magnitude.

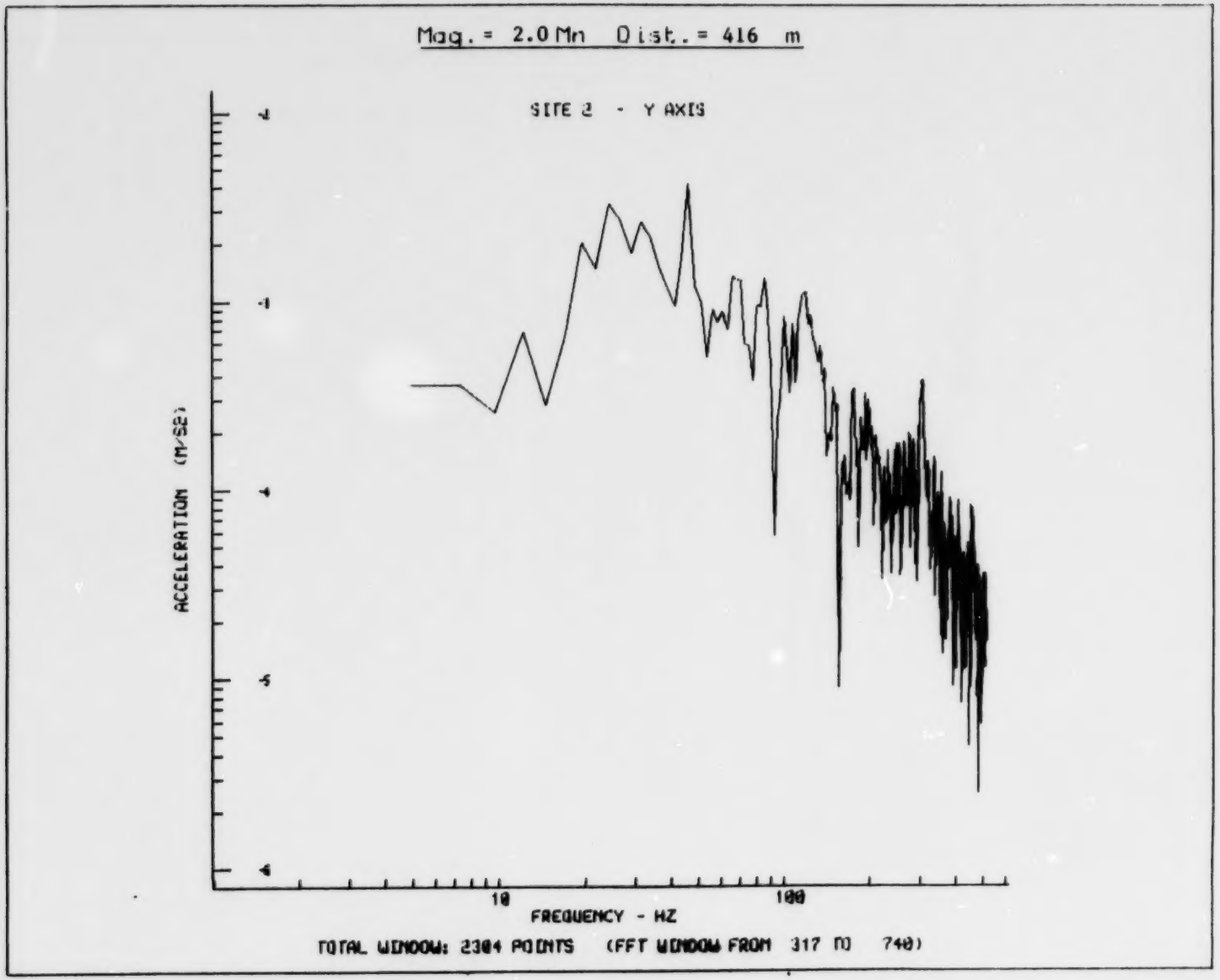


Fig. 1.2.2 - Log acceleration versus log frequency for north/south axis at 2.0 magnitude.

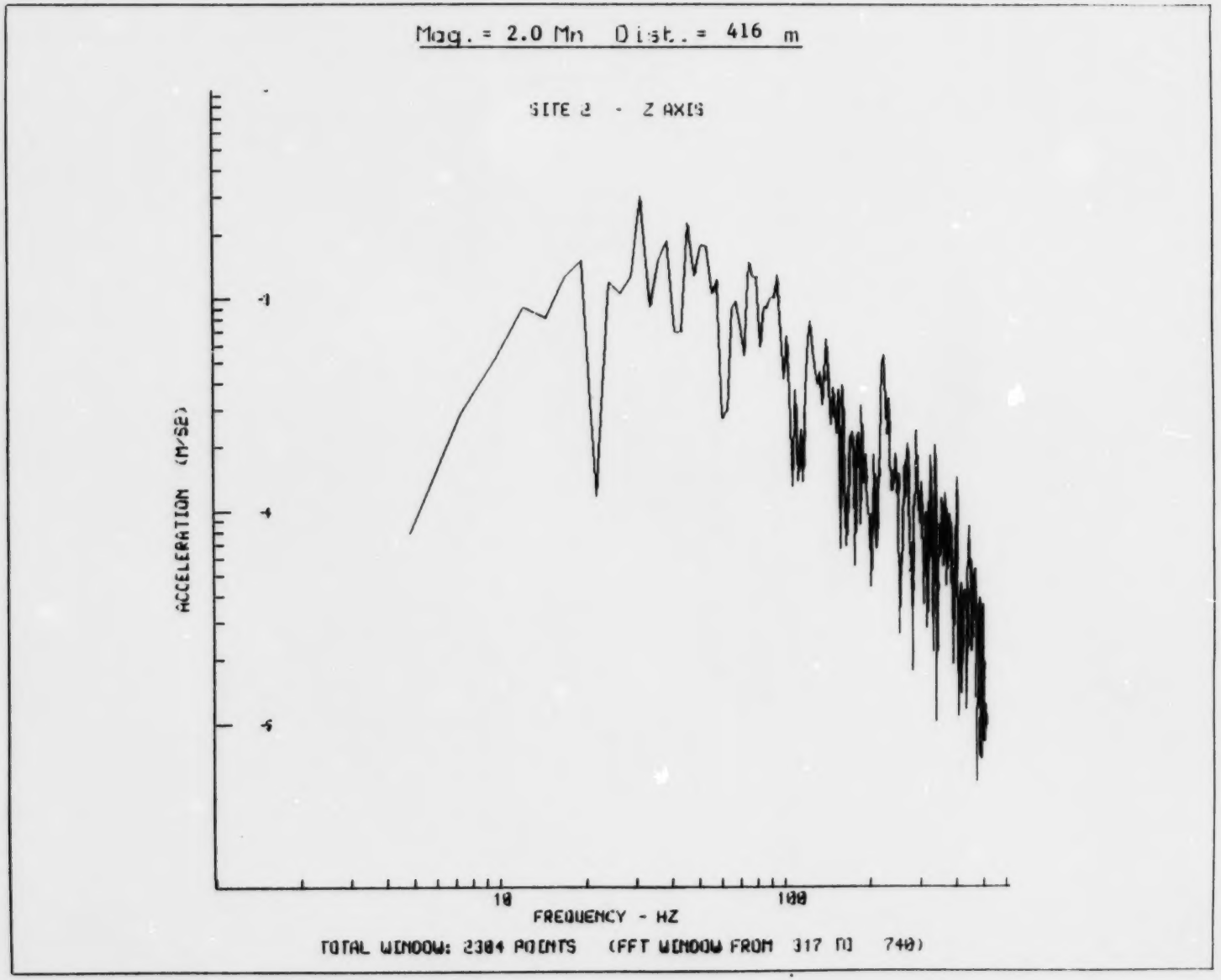


Fig. 1.2.3 - Log acceleration versus log frequency for elevation at 2.0 magnitude.

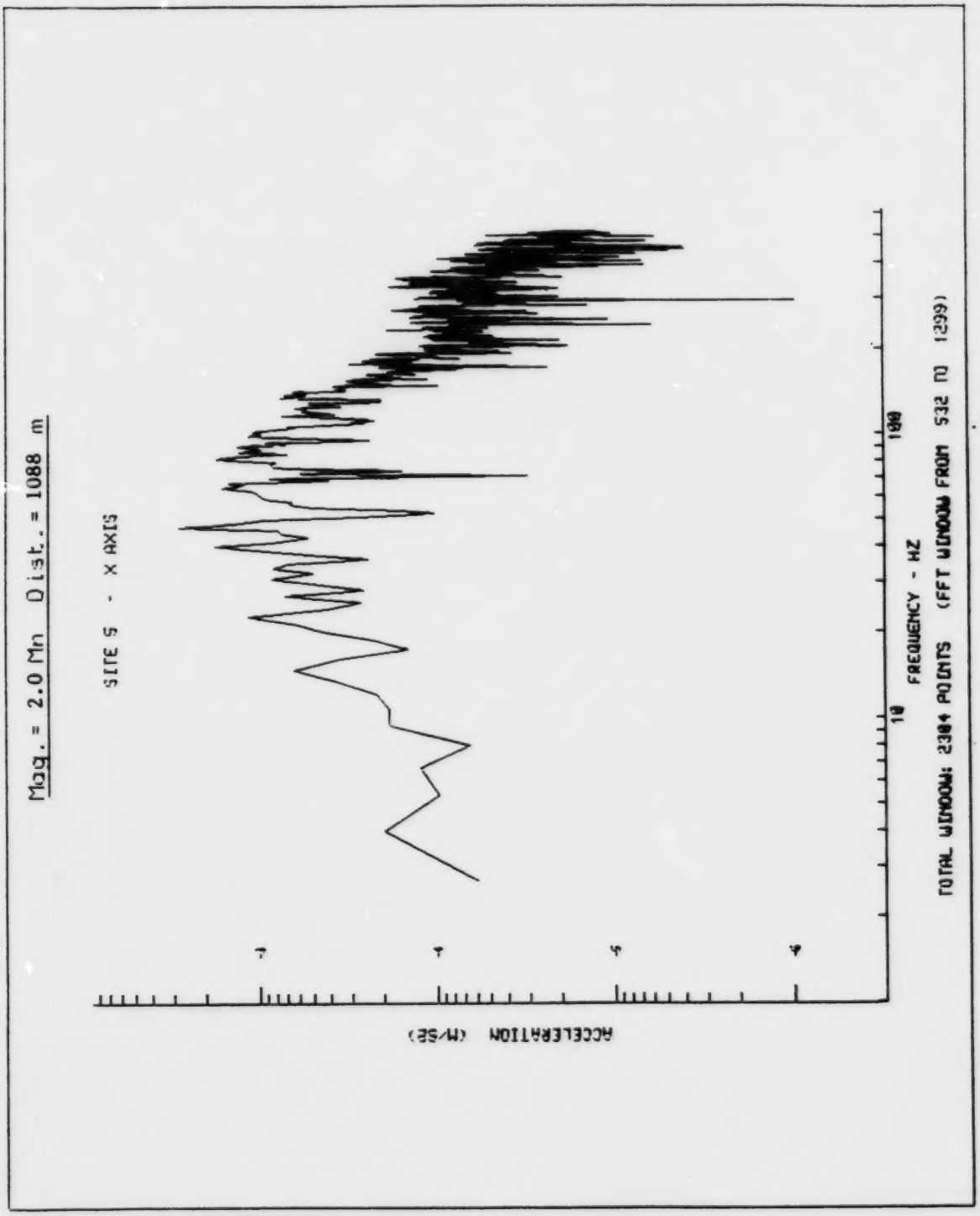


Fig. 1.3.1. - Log acceleration versus log frequency for east/west axis at 2.0 magnitude.

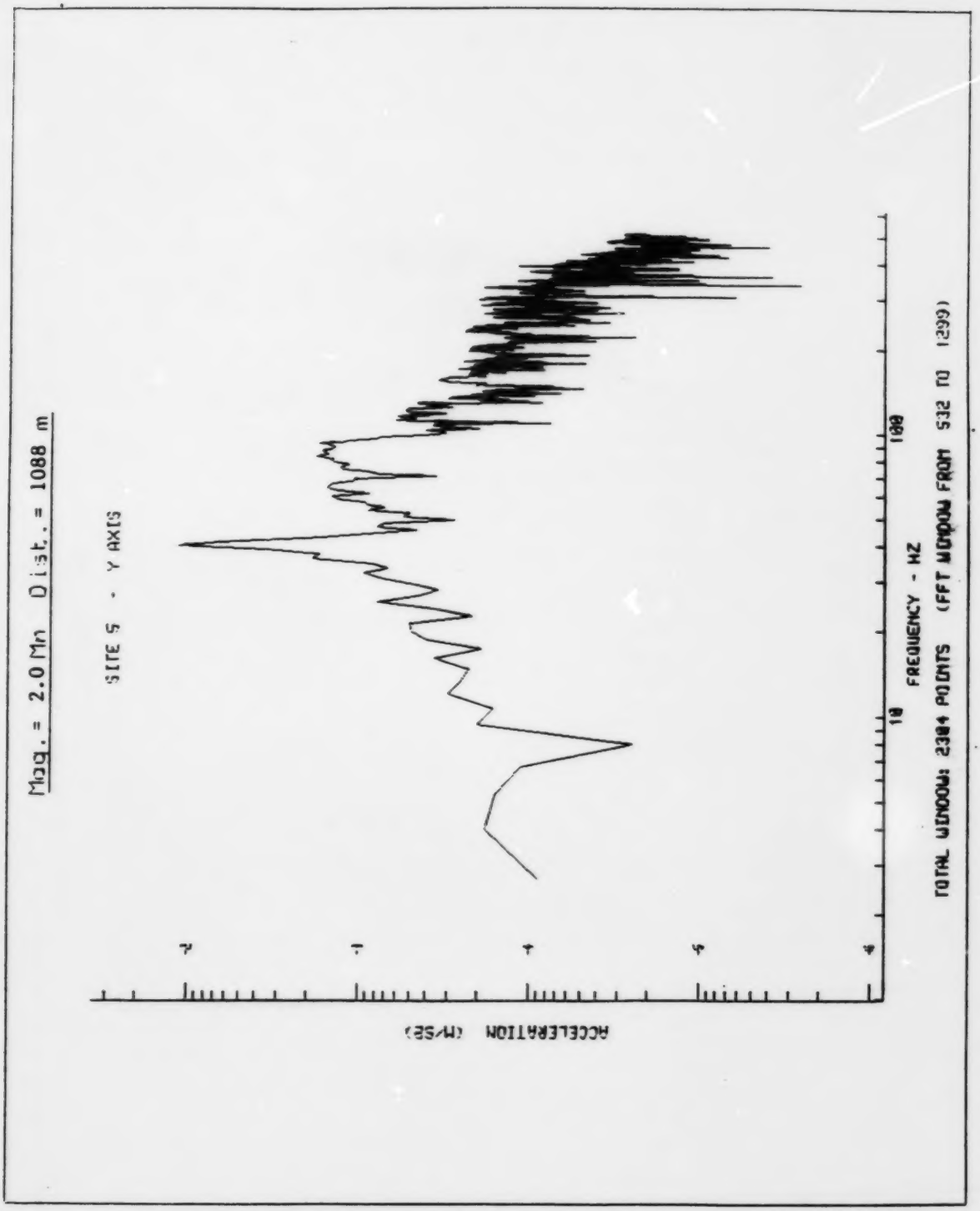


Fig. 1.3.2 - Log acceleration versus log frequency for north/south axis at 2.0 magnitude.

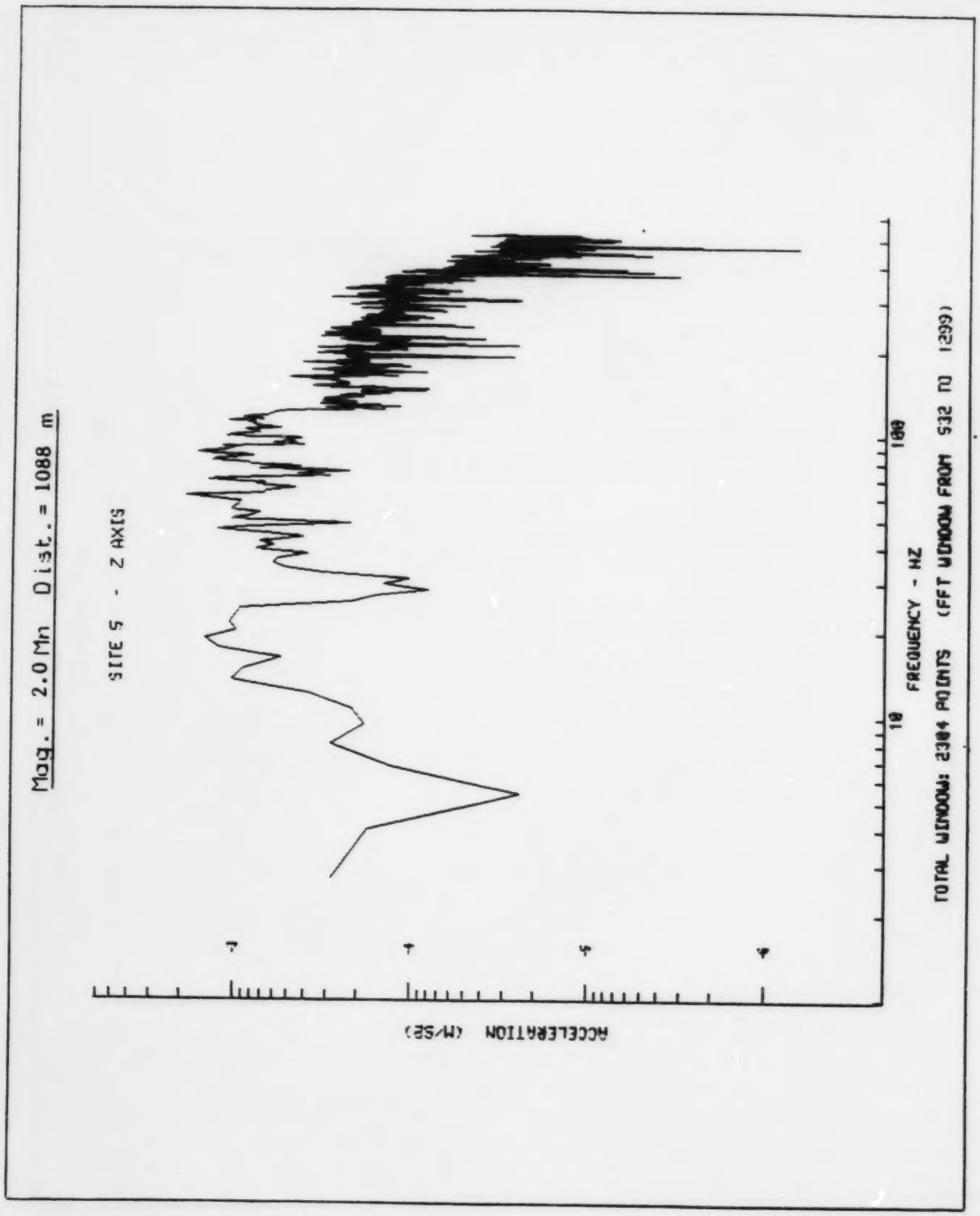


Fig. 1.3.3 - Log acceleration versus log frequency for elevation at 2.0 magnitude.

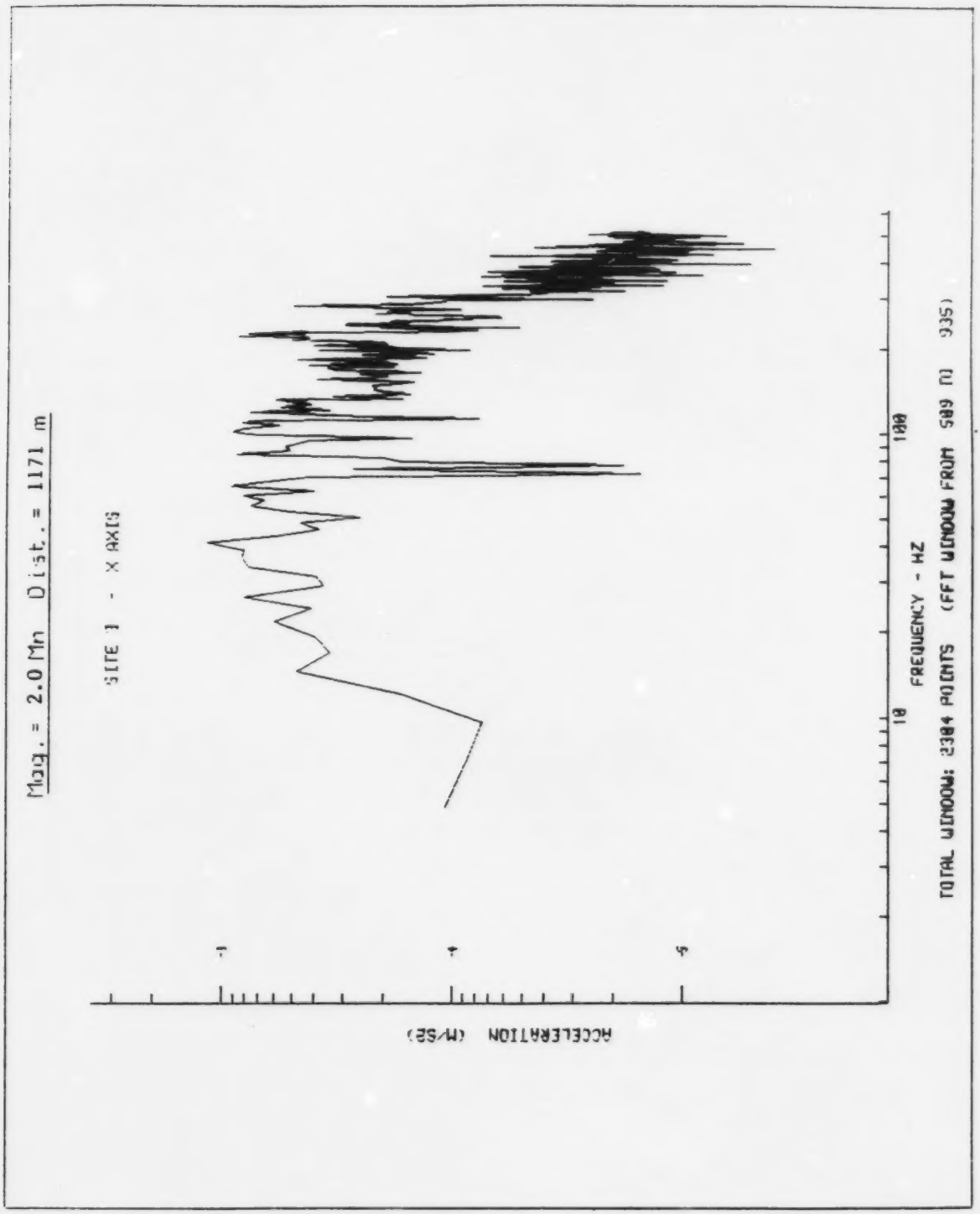


Fig. 1.4.1 - Log acceleration versus log frequency for east/west axis at 2.0 magnitude.

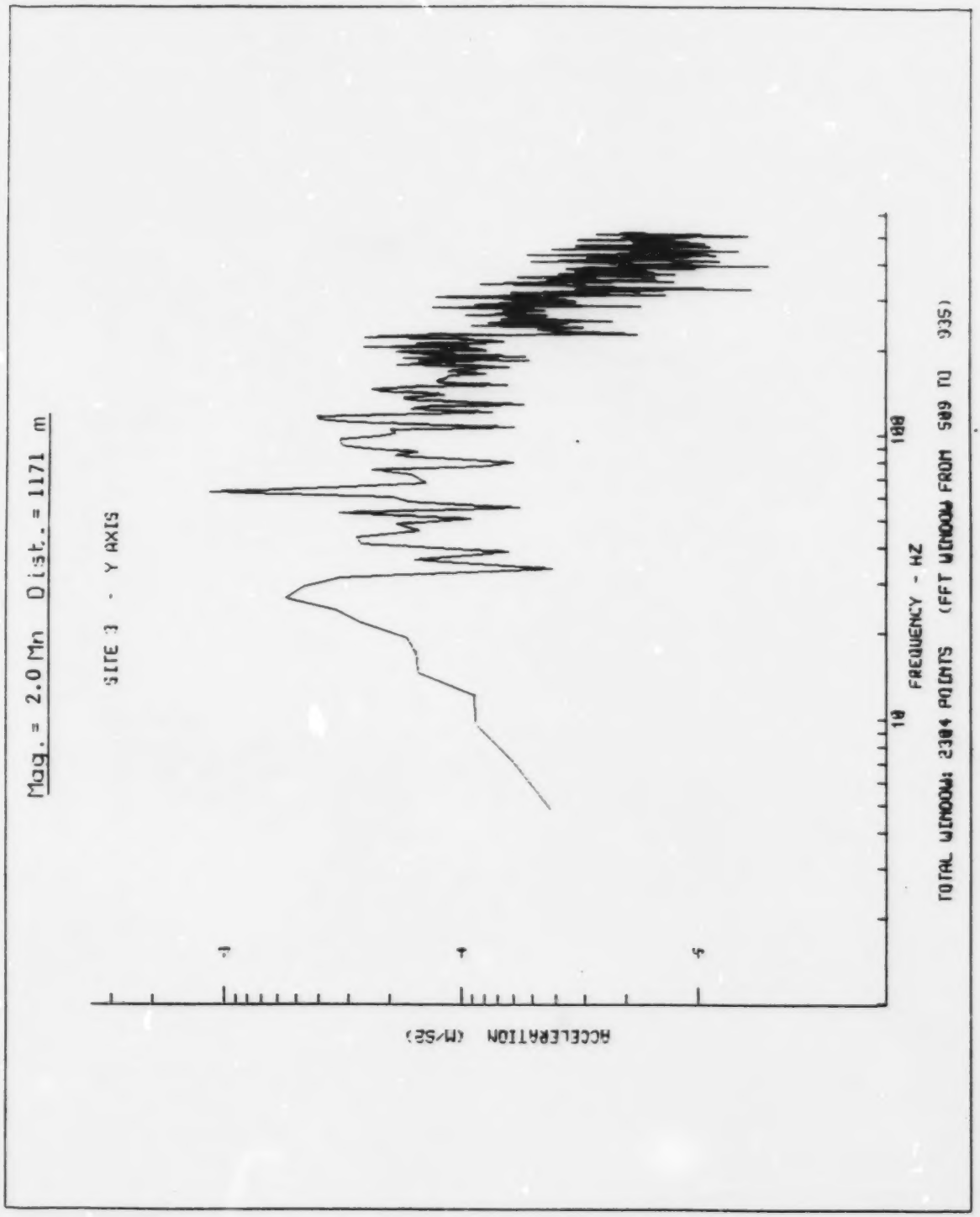


Fig. 1.4.2 - Log acceleration versus log frequency for north/south axis at 2.0 magnitude.

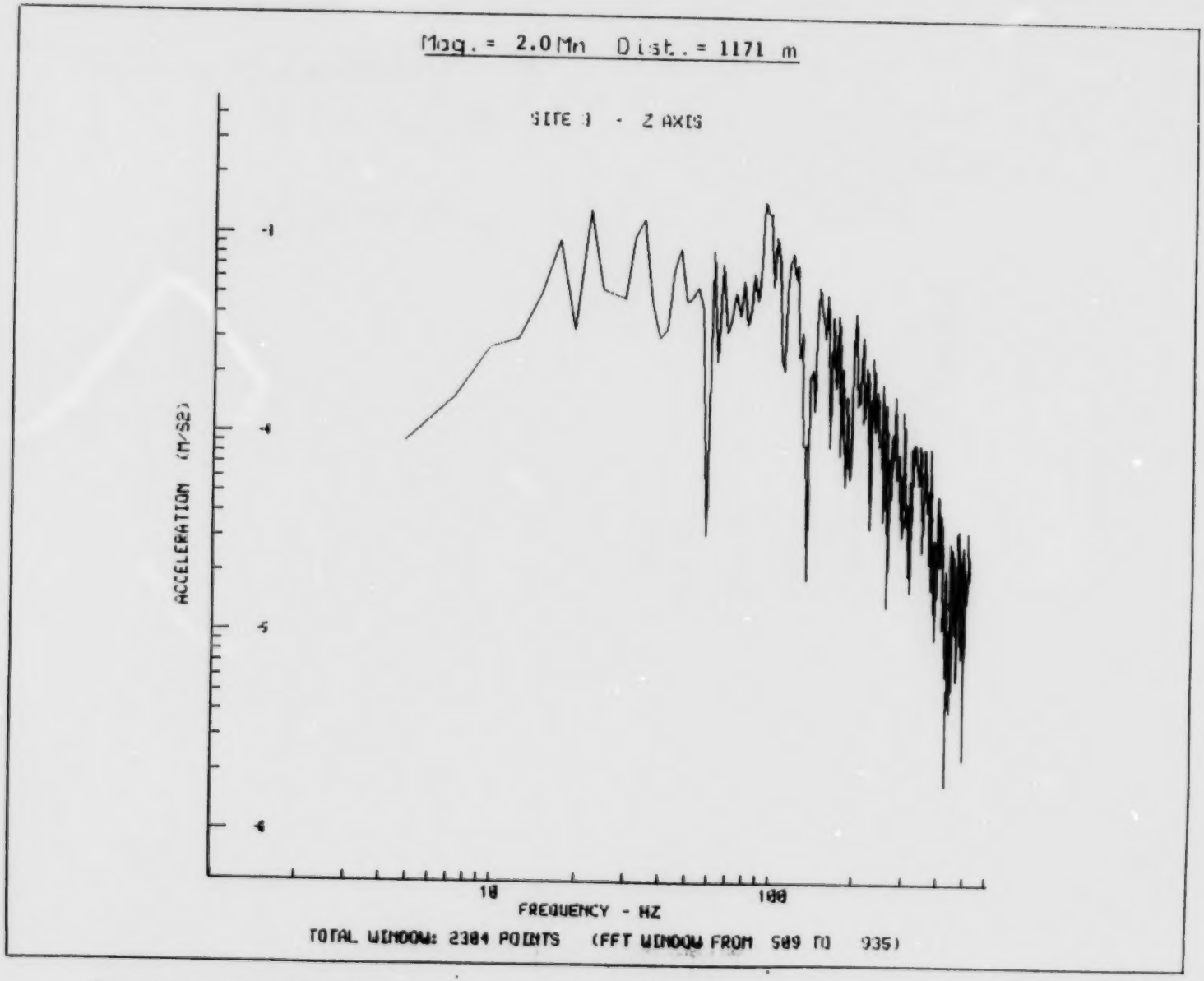


Fig. 1.4.3 - Log acceleration versus log frequency for elevation at 2.0 magnitude.

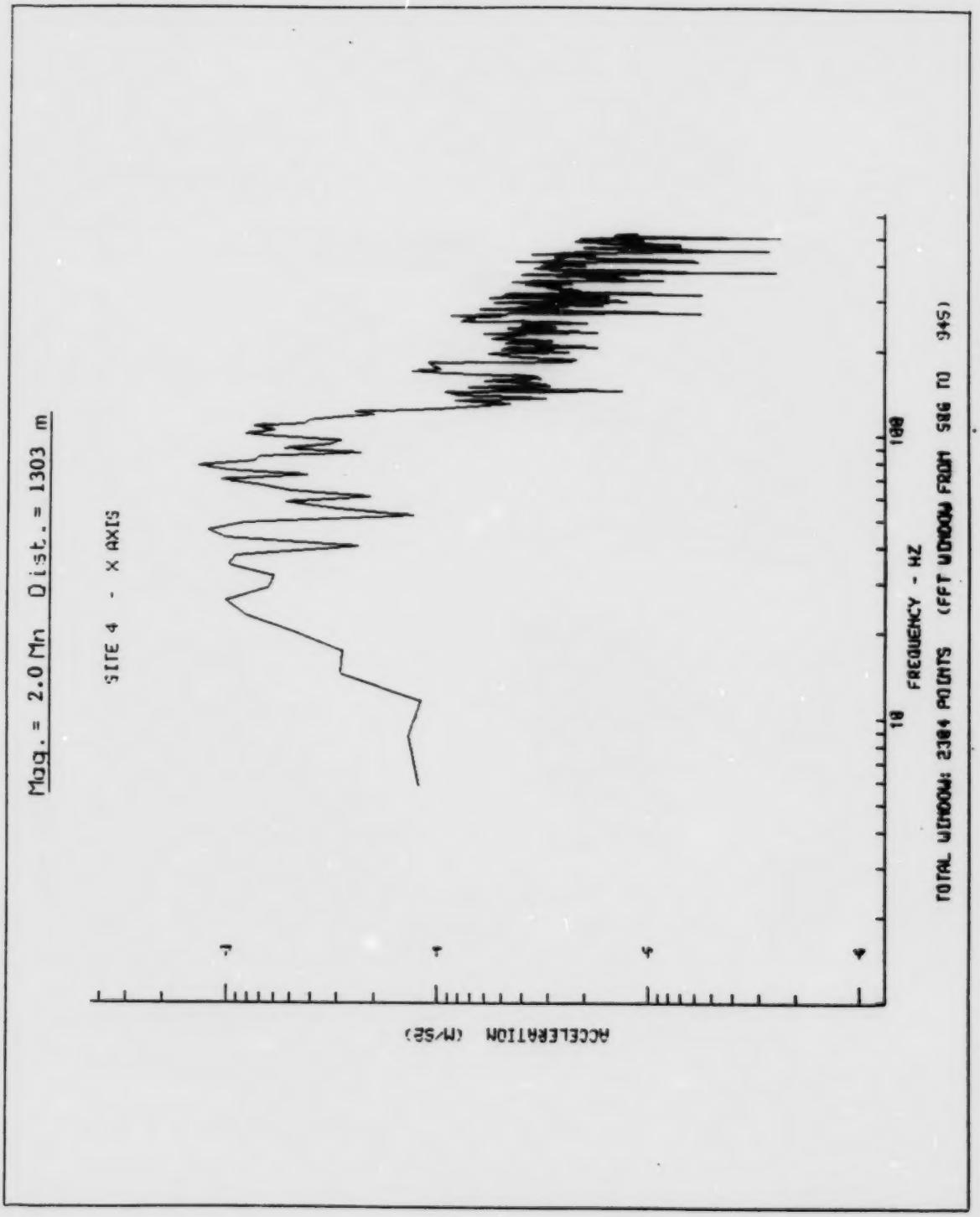


Fig. 1.5.1 - Log acceleration versus log frequency for east/west axis at 2.0 magnitude.

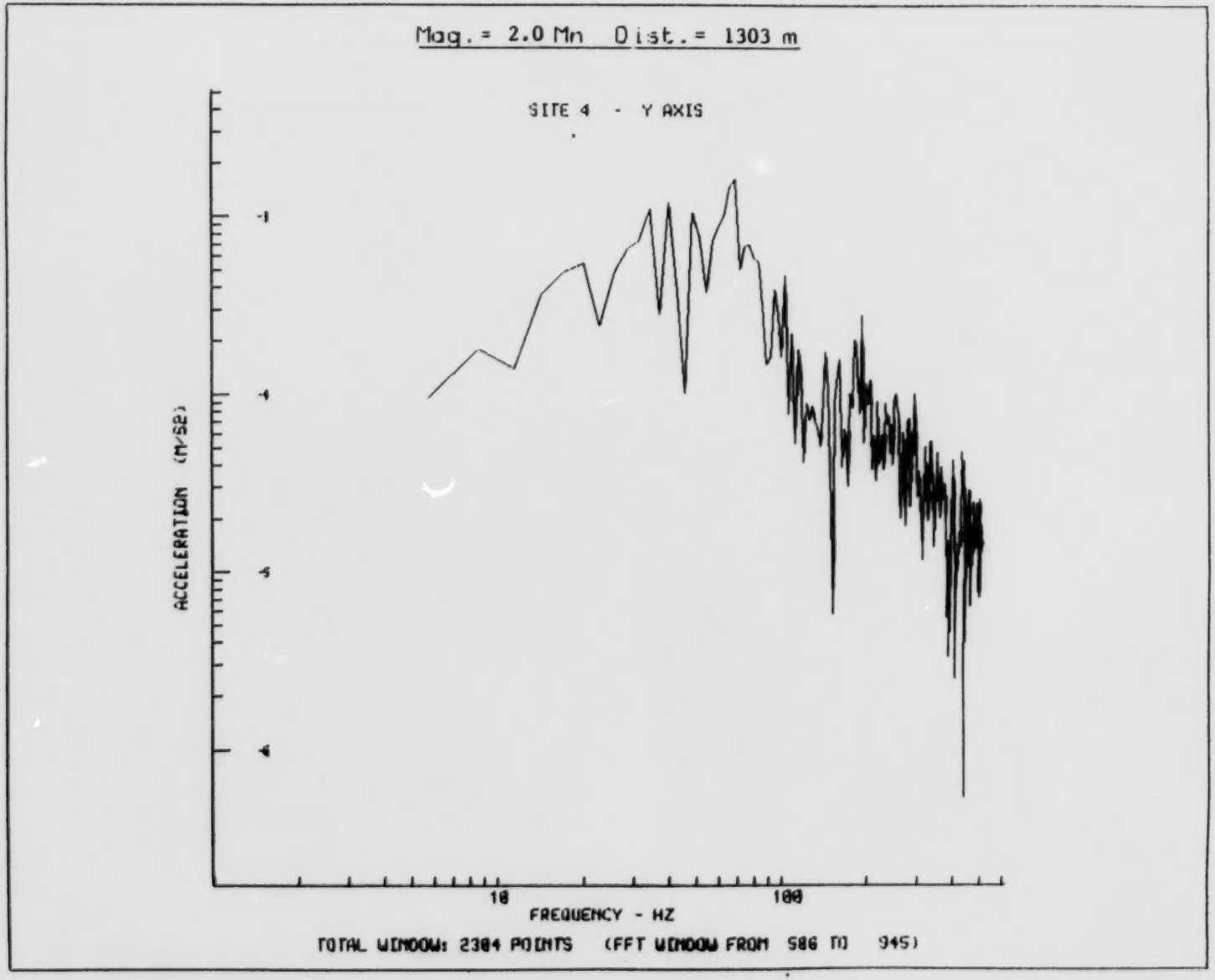


Fig. 1.5.2 - Log acceleration versus log frequency for north/south axis at 2.0 magnitude.

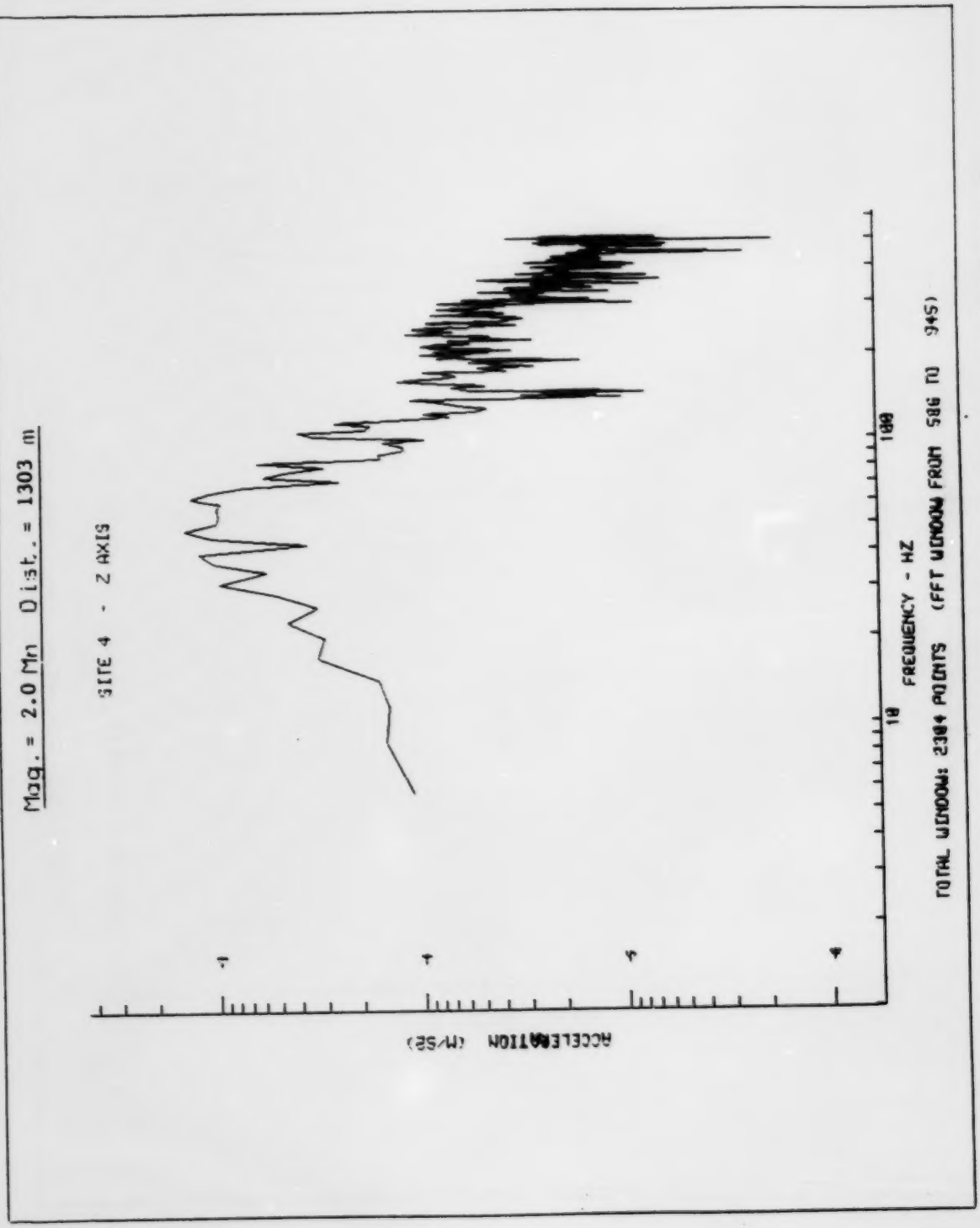


Fig. 1.5.3 - Log acceleration versus log frequency for elevation at 2.0 magnitude.

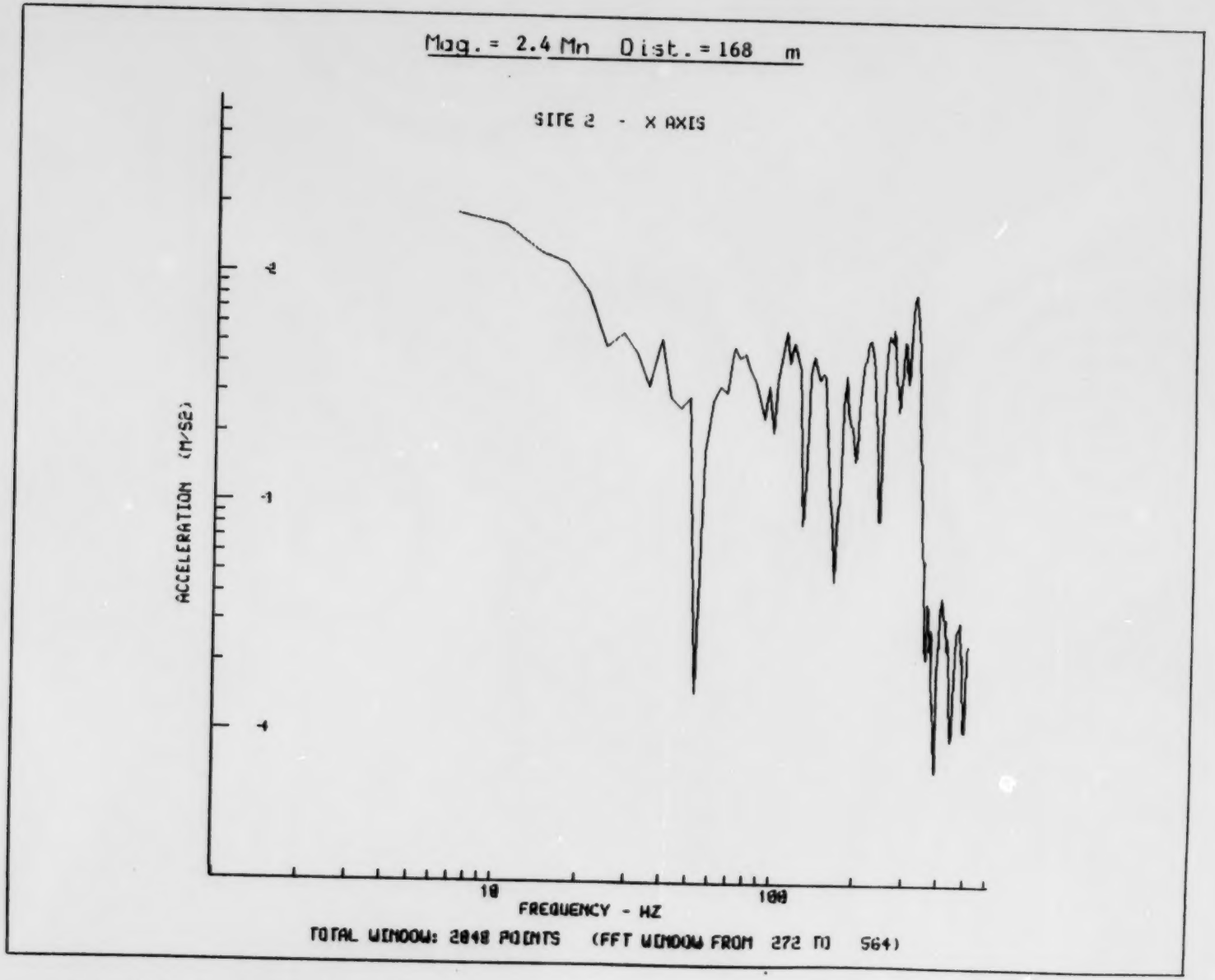


Fig. 2.1.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude,

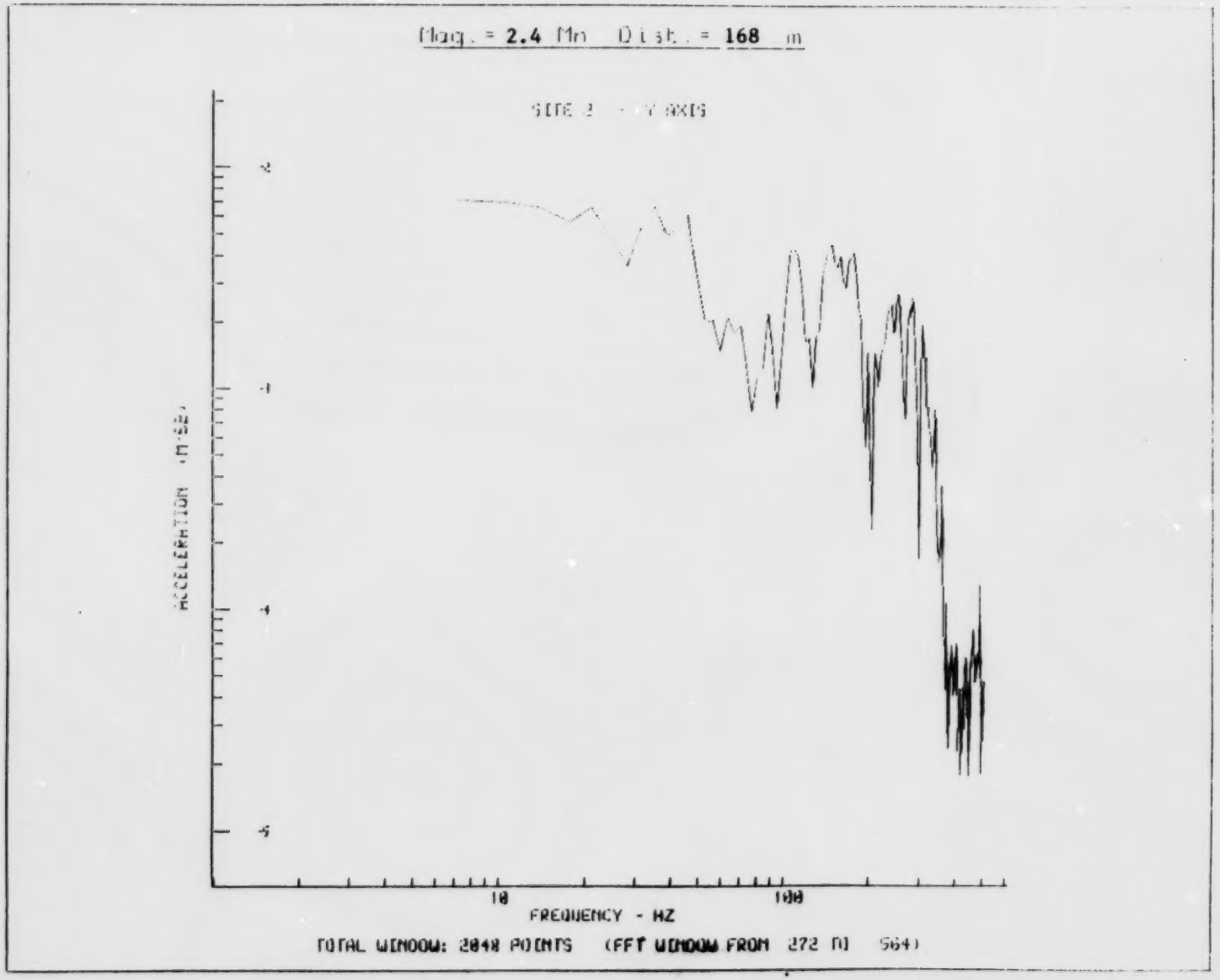


Fig. 2.1.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

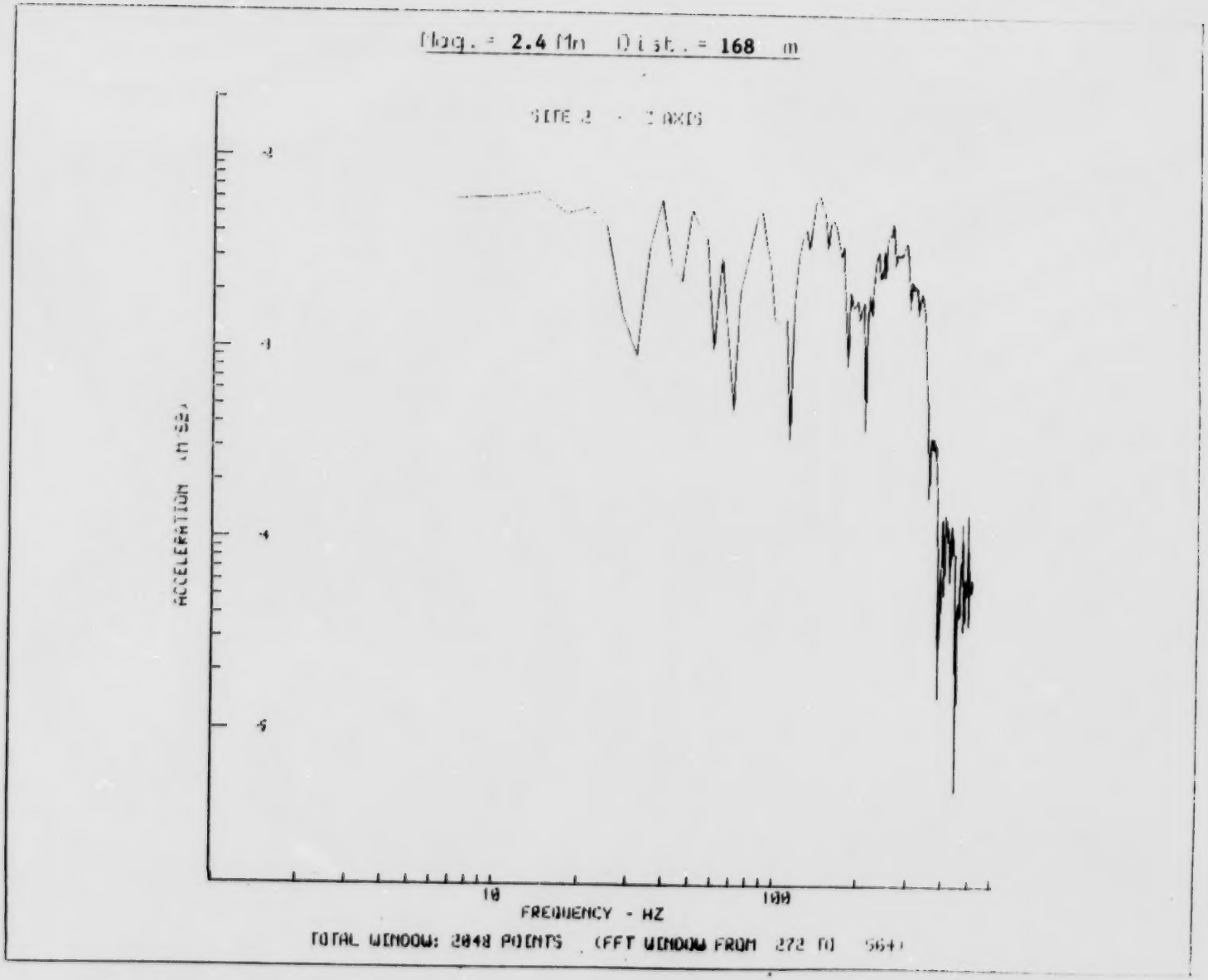


Fig. 2.1.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

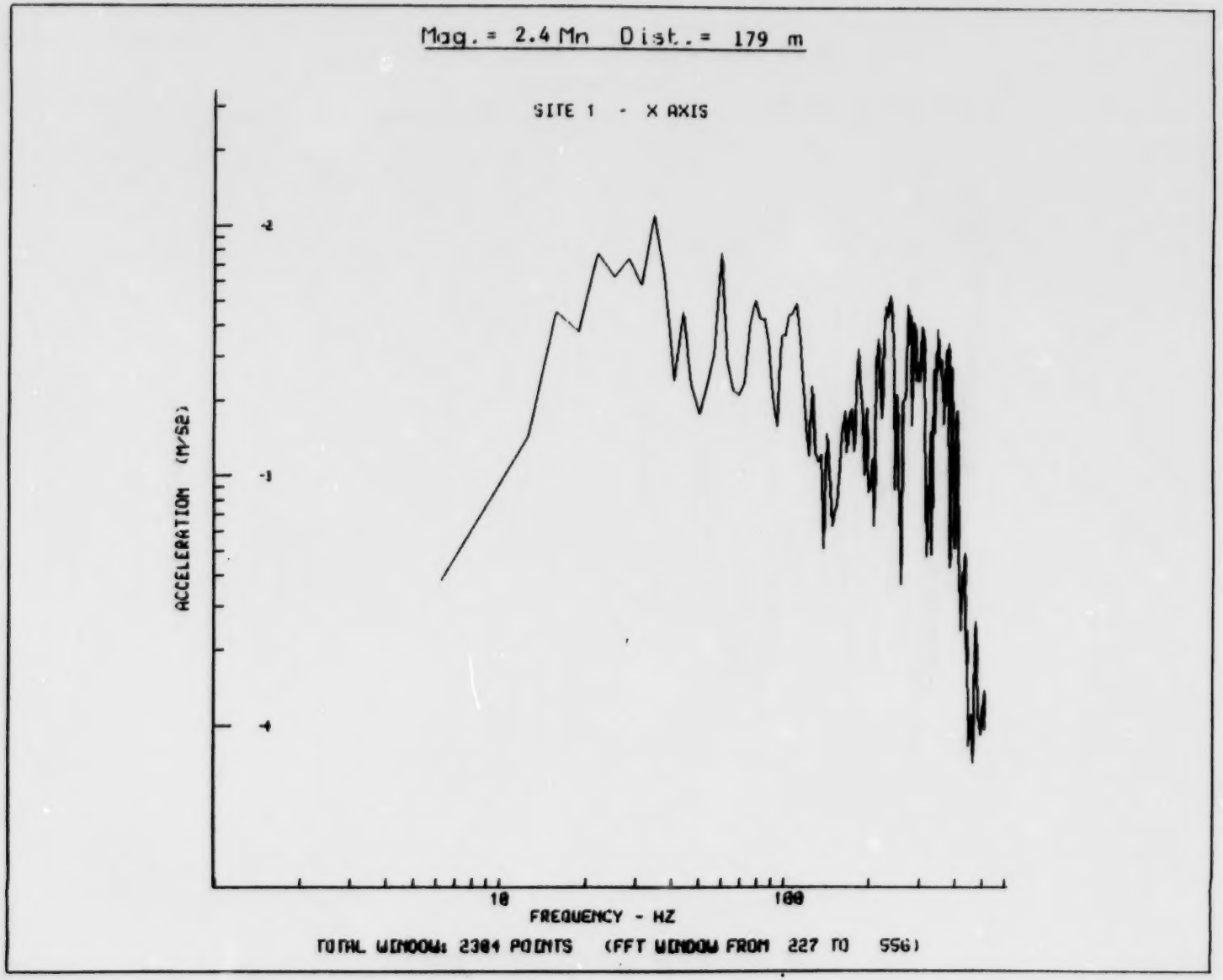


Fig. 2.2.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

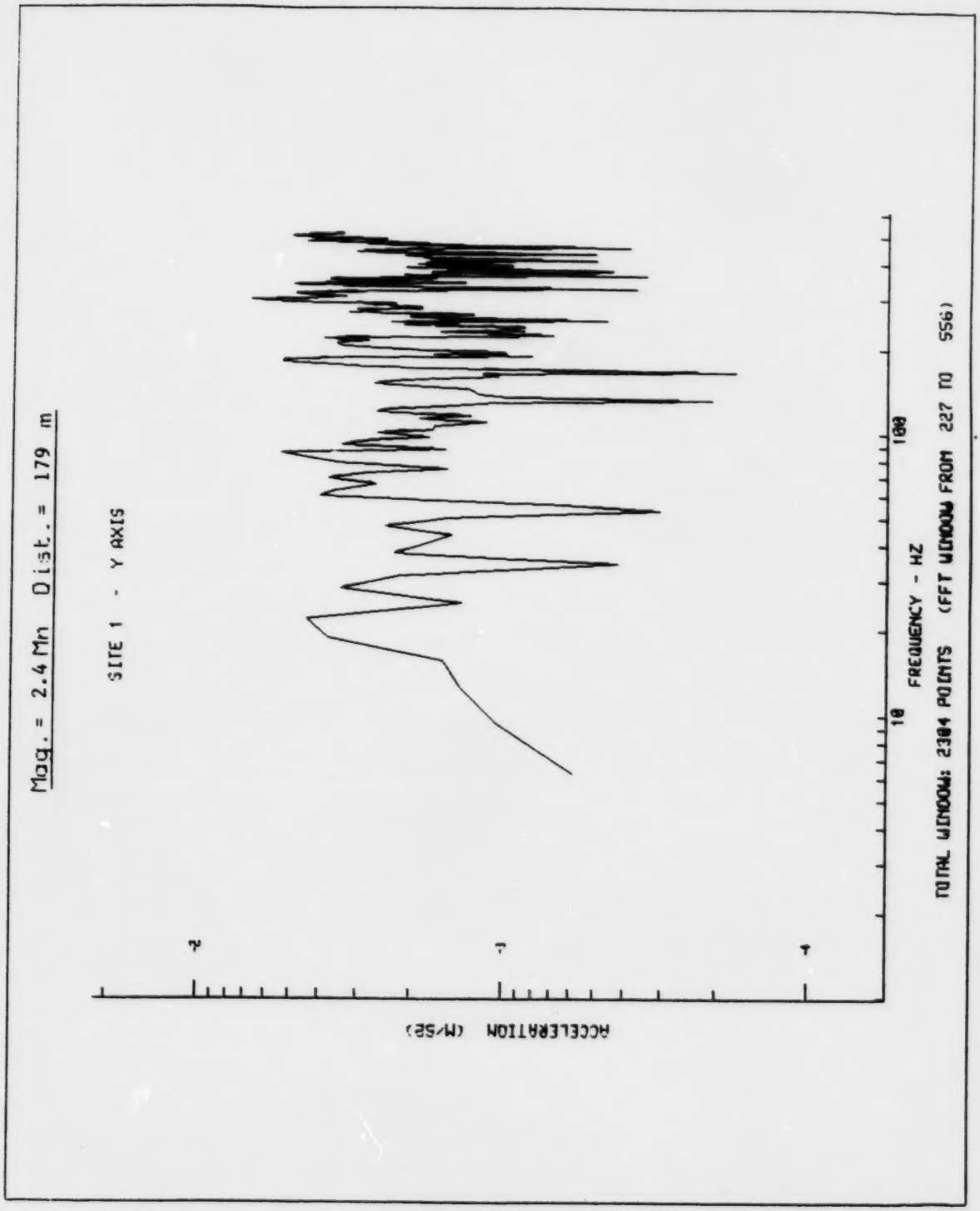


Fig. 2.2.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

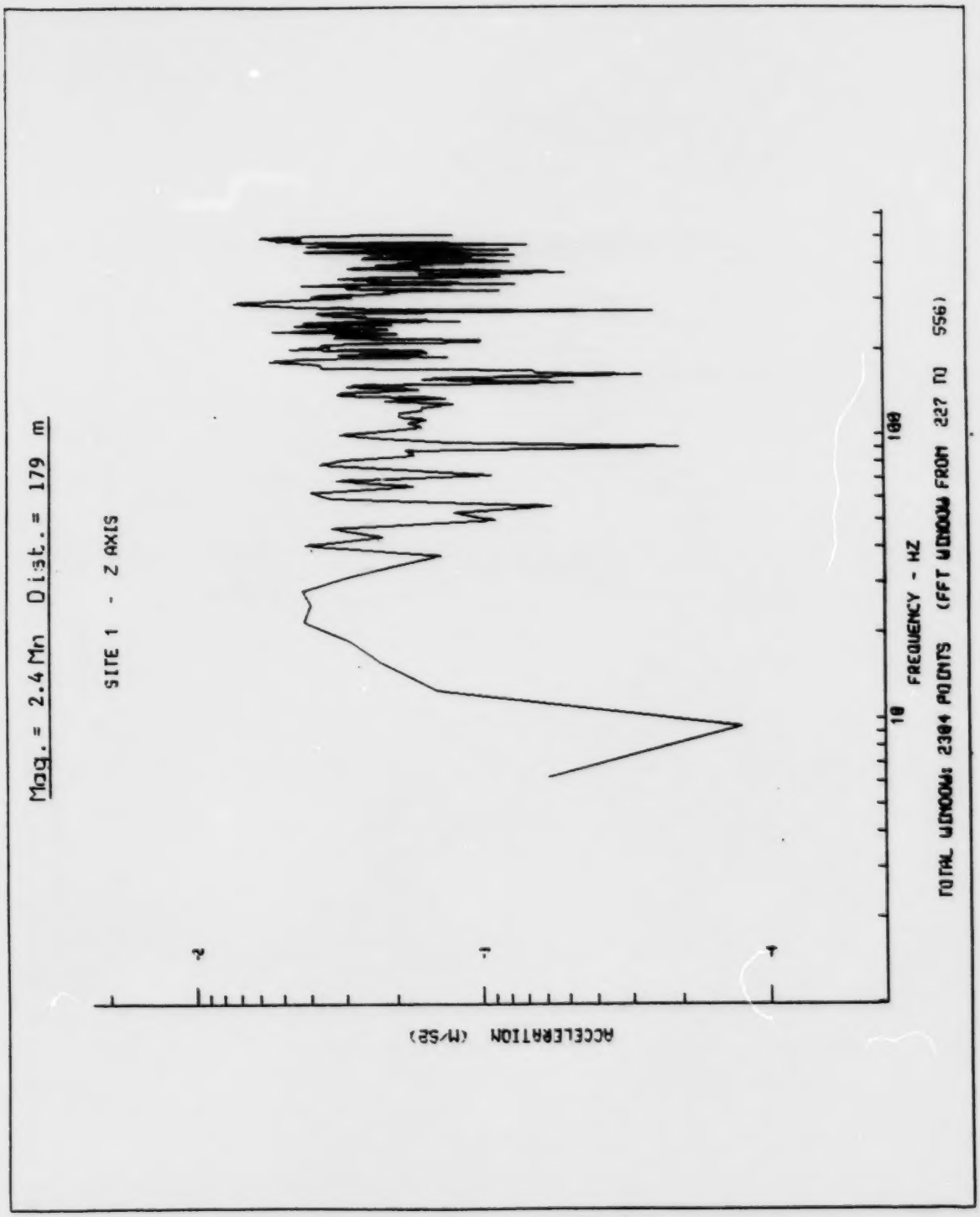
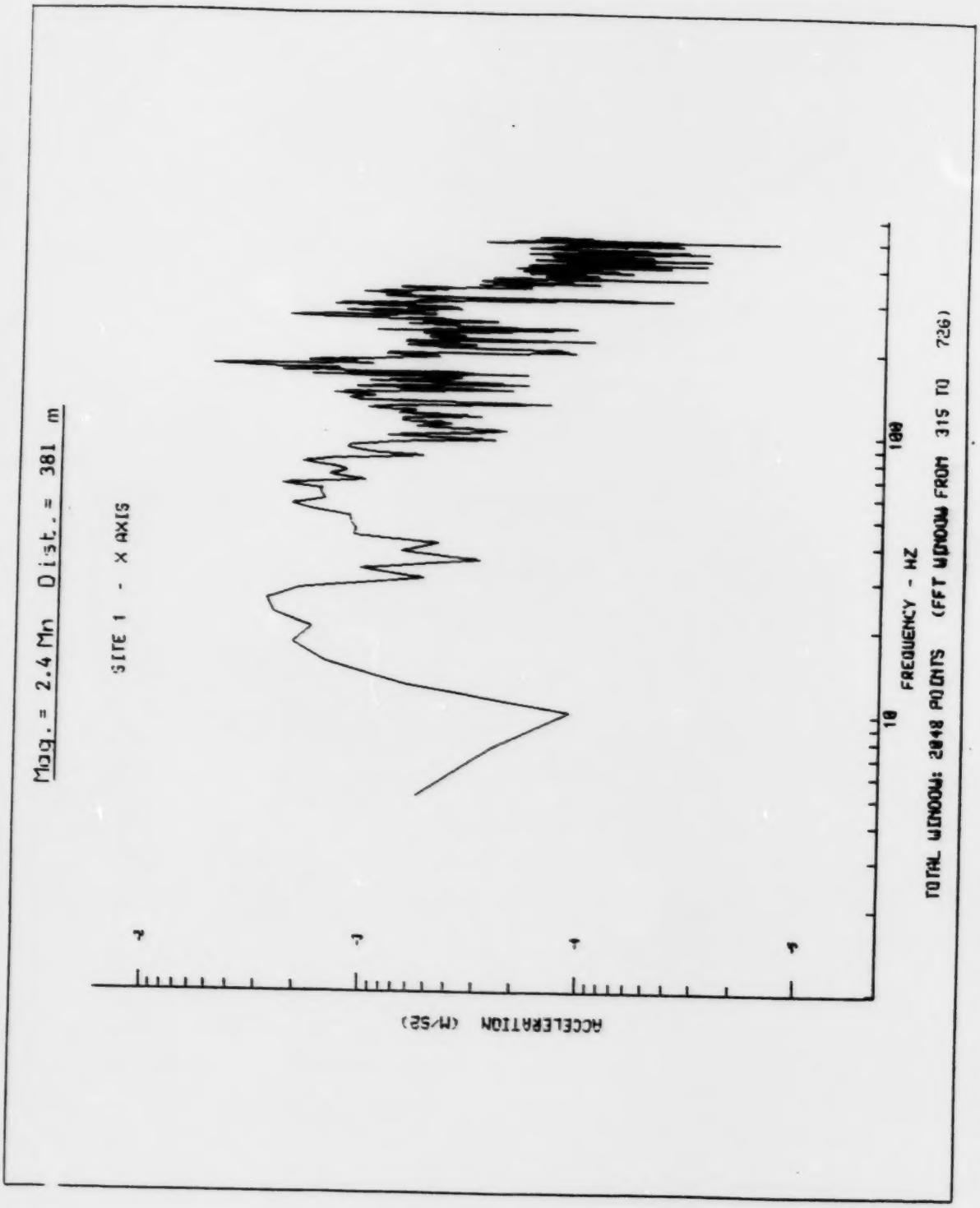


Fig. 2.2.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude



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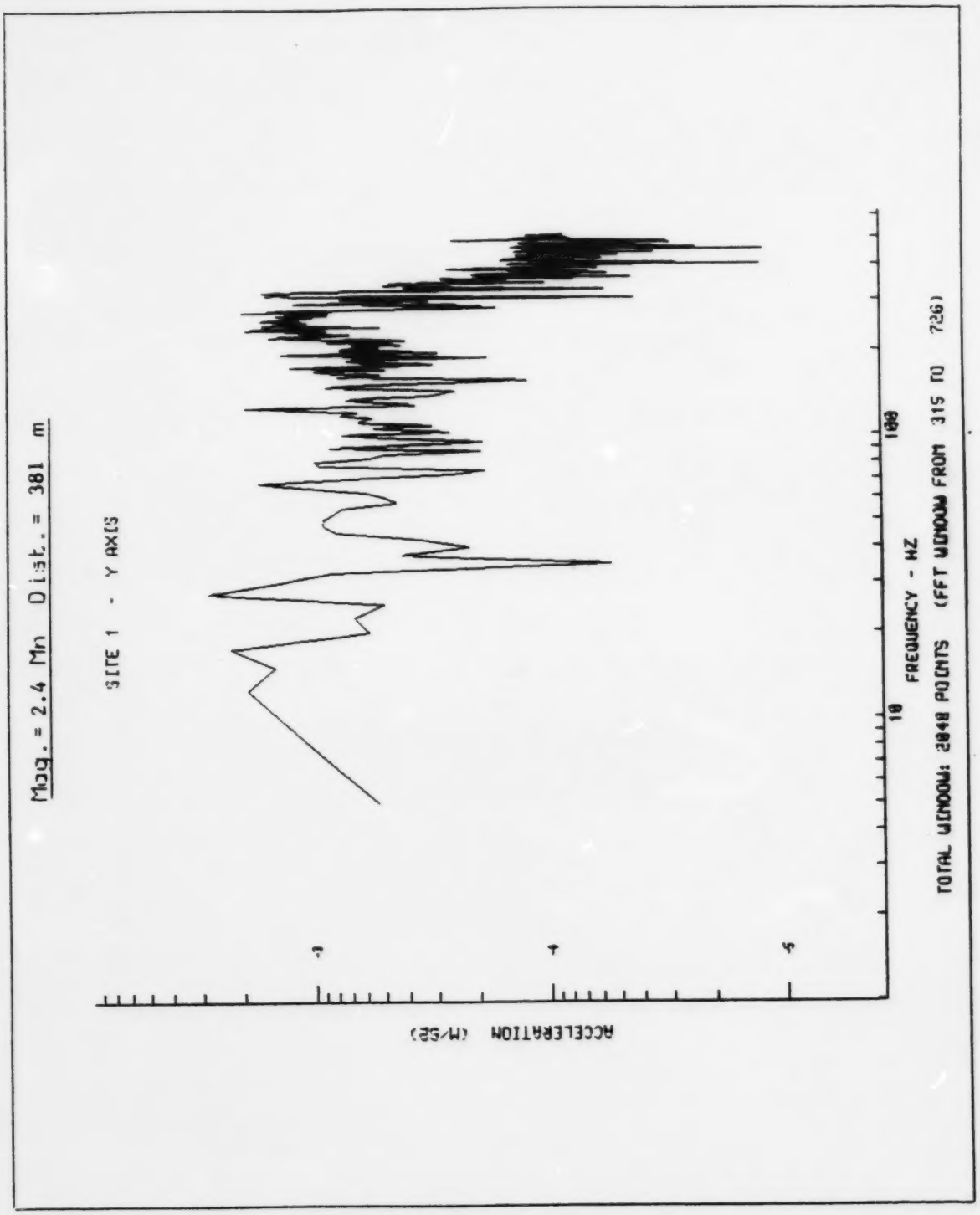

Fig. 2.3.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

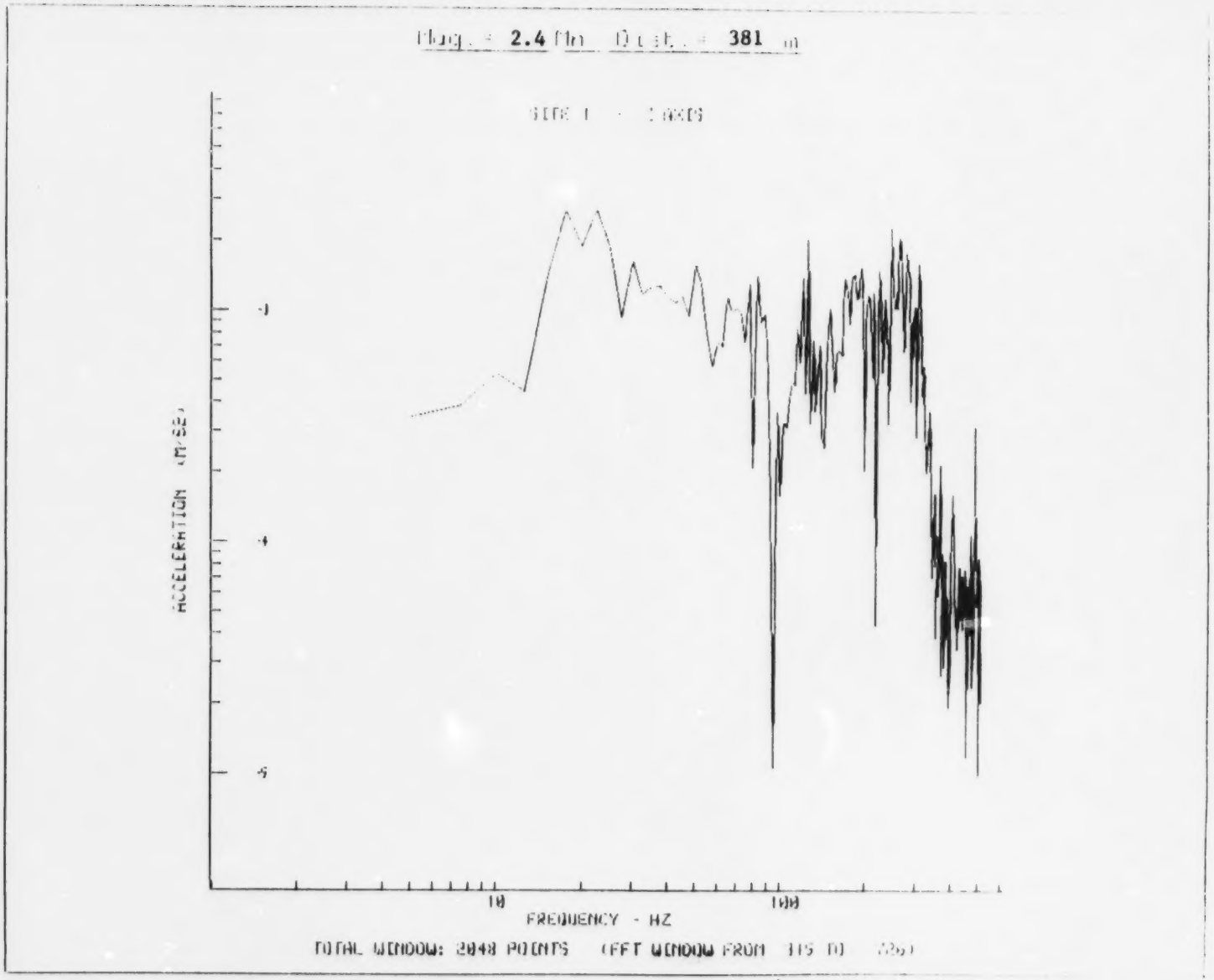

Fig. 2.3.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

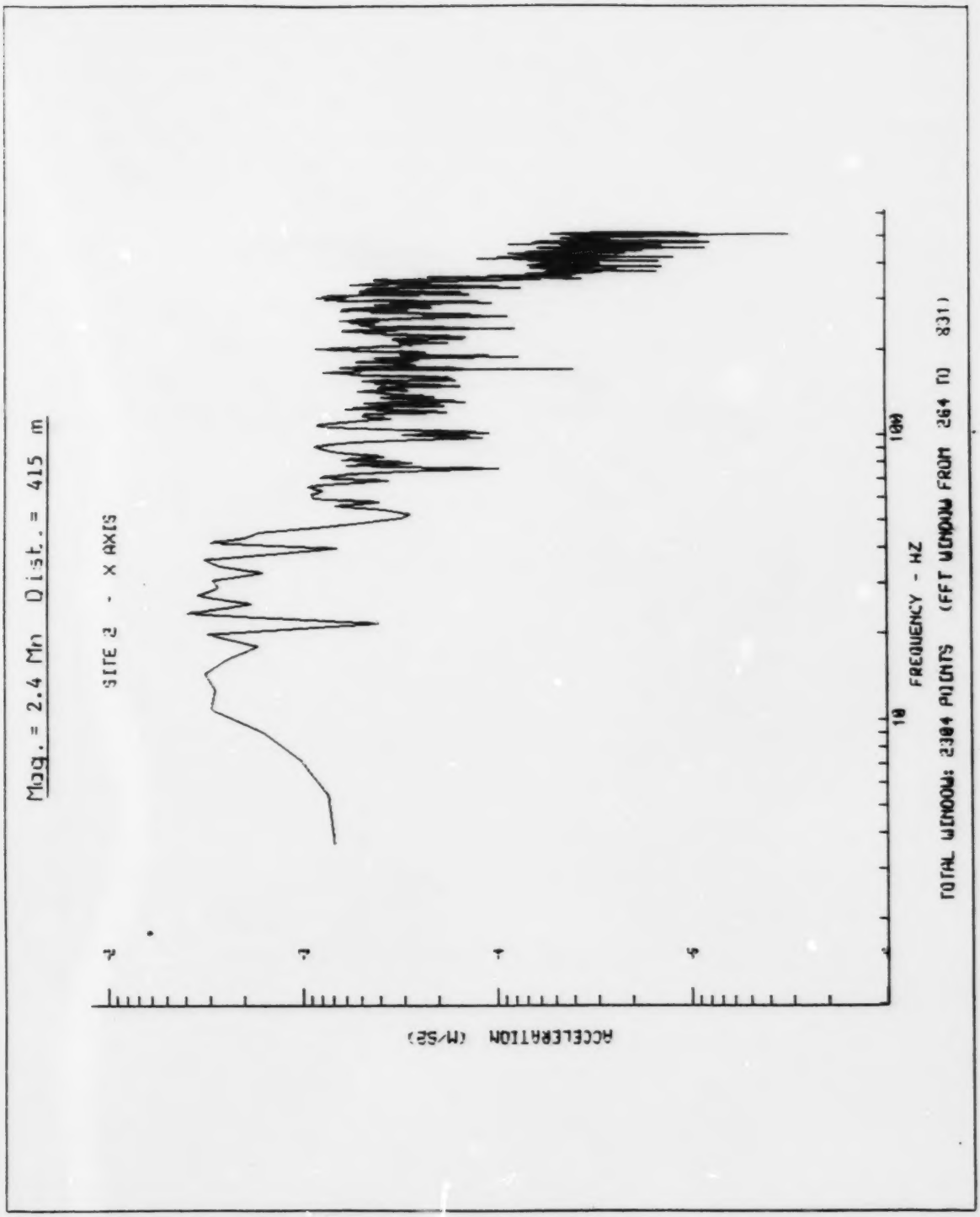

Fig. 2.4.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

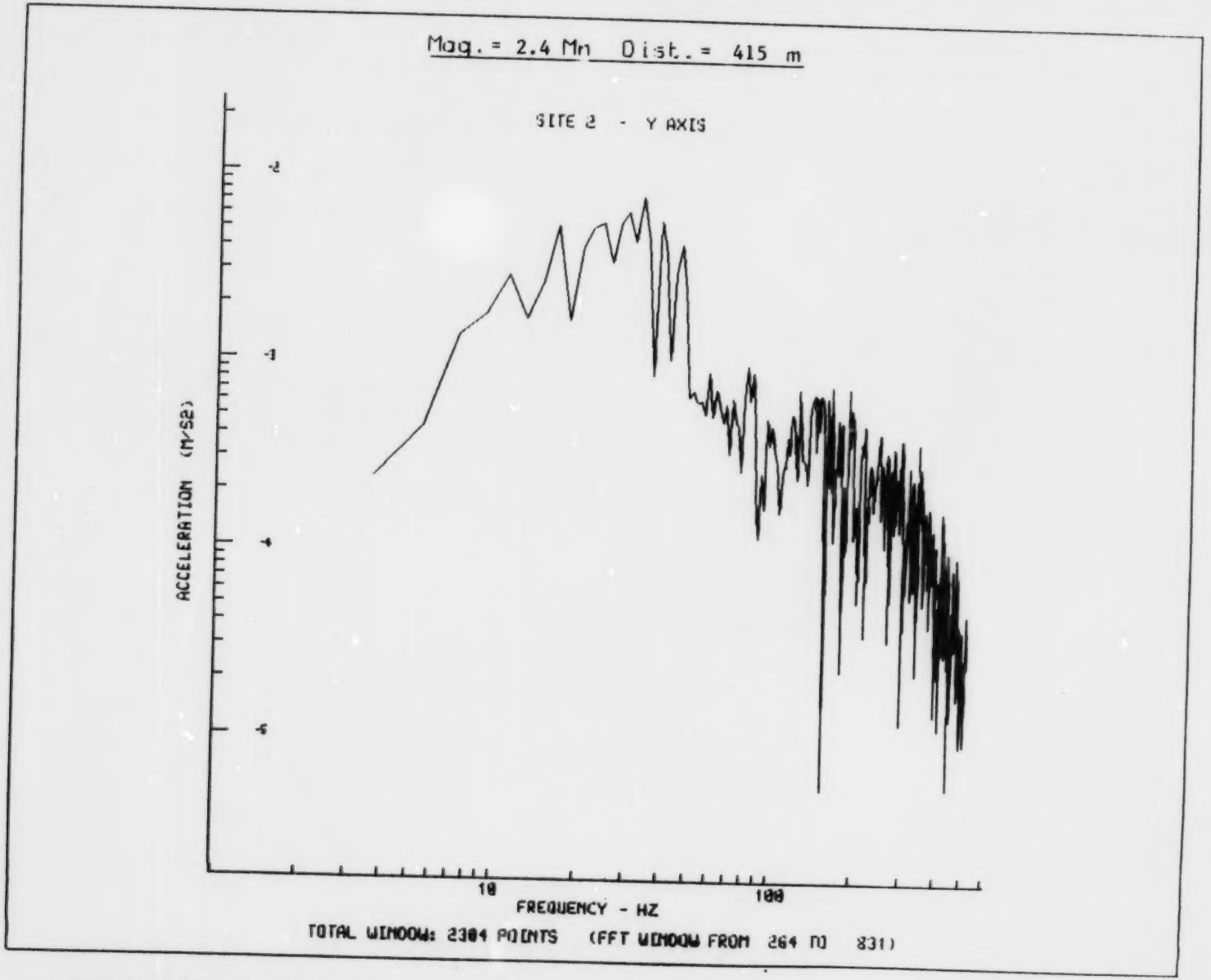

Fig. 2.4.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

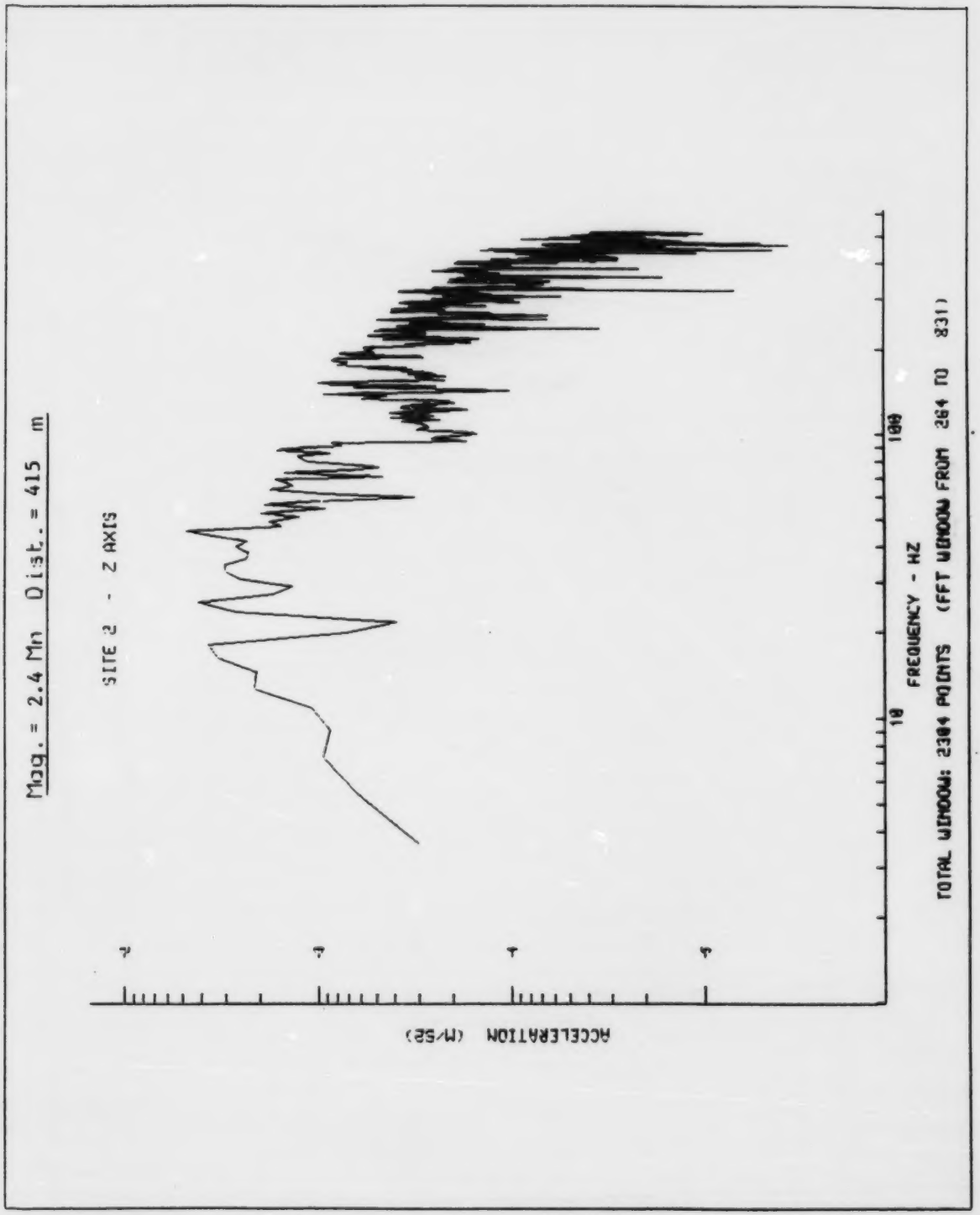

Fig. 2.4.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

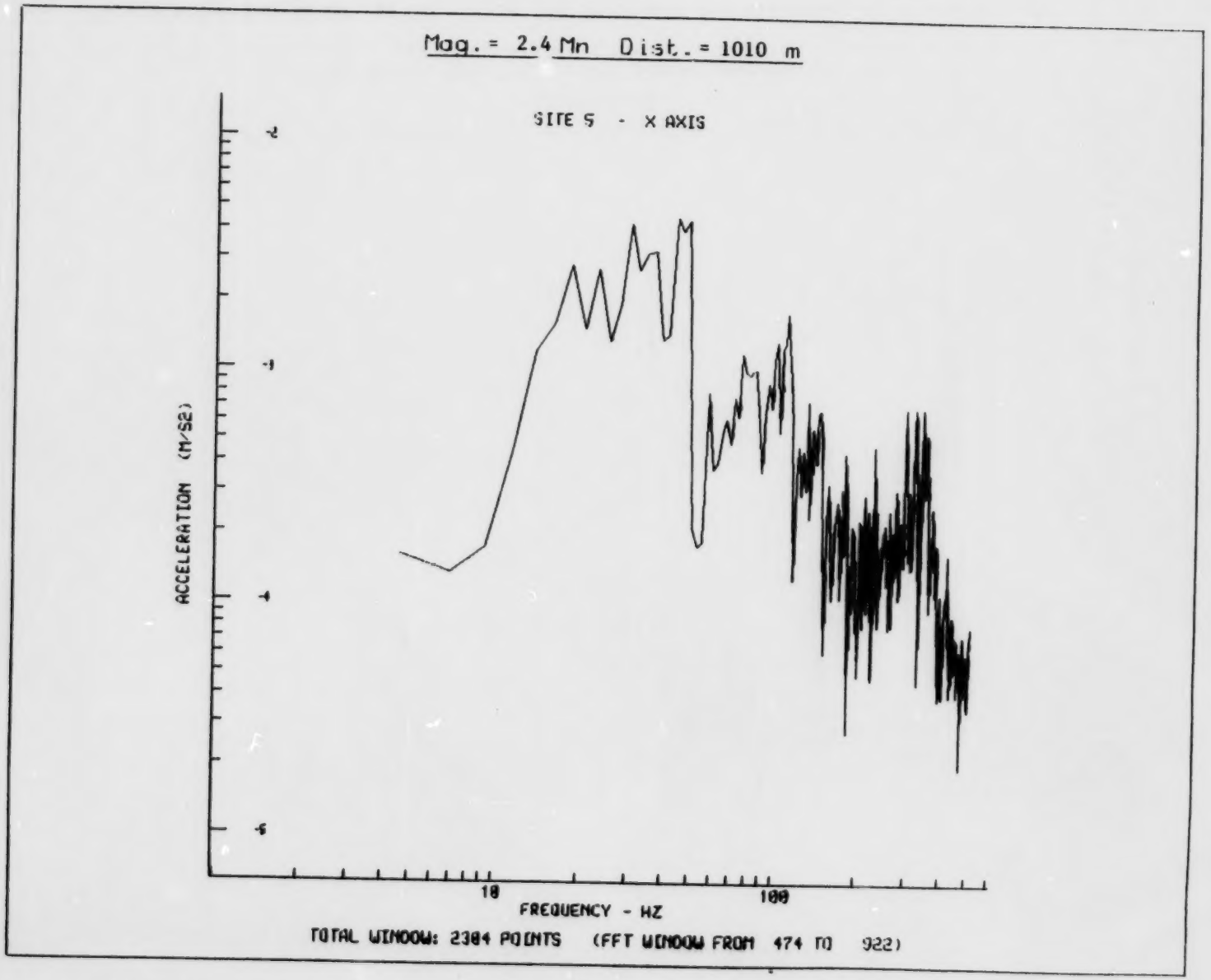

Fig. 2.5.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

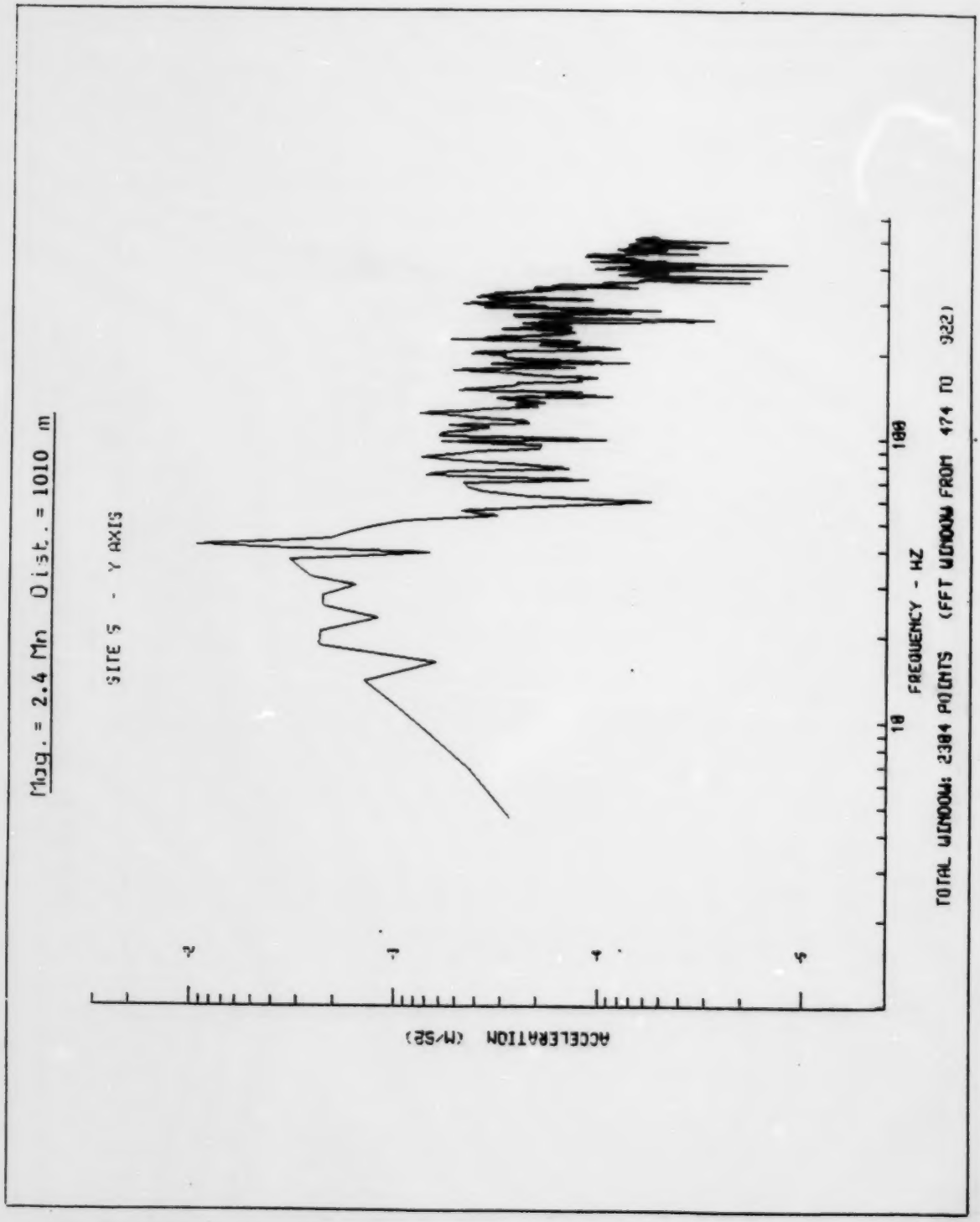

Fig. 2.5.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

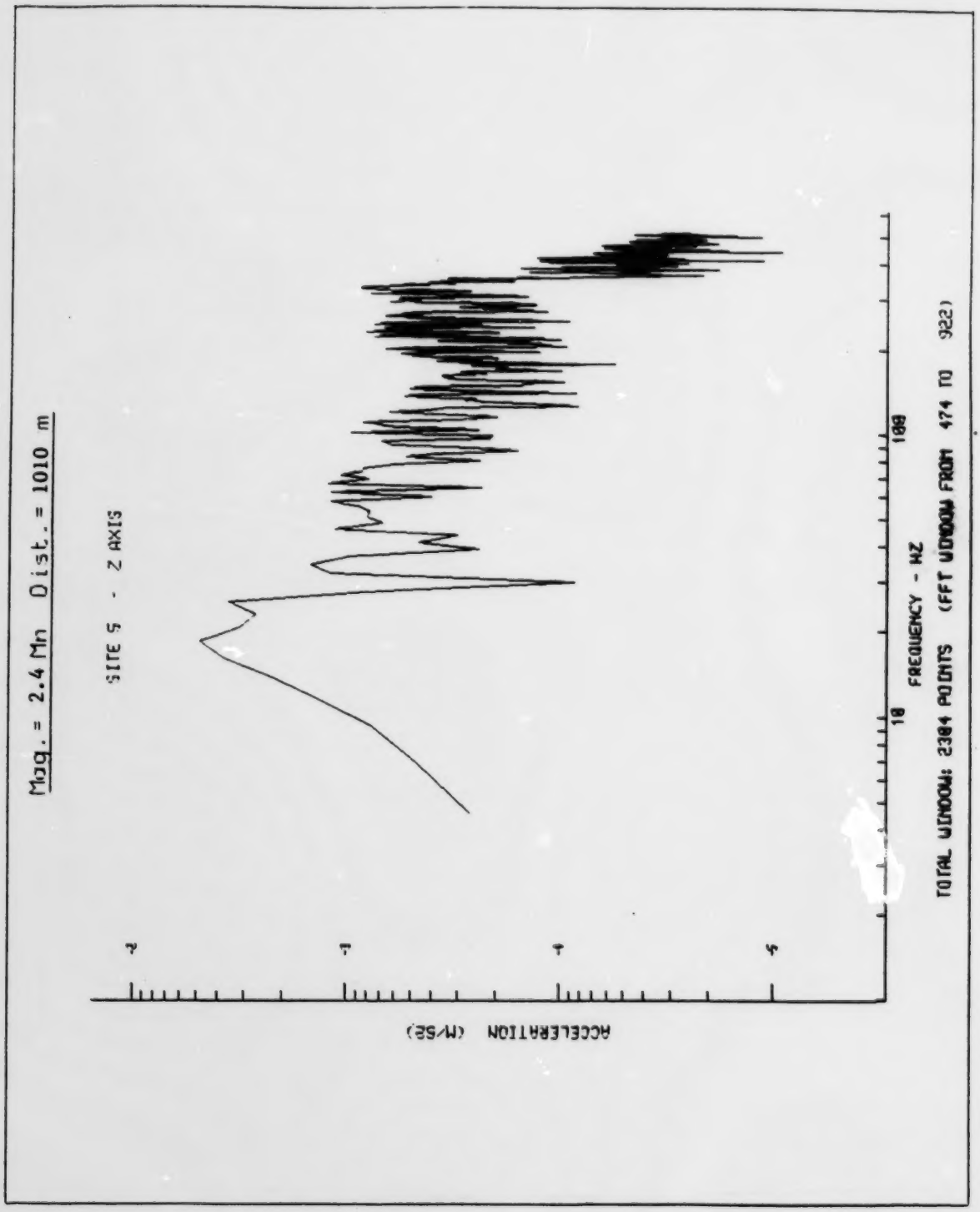

Fig. 2.5.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

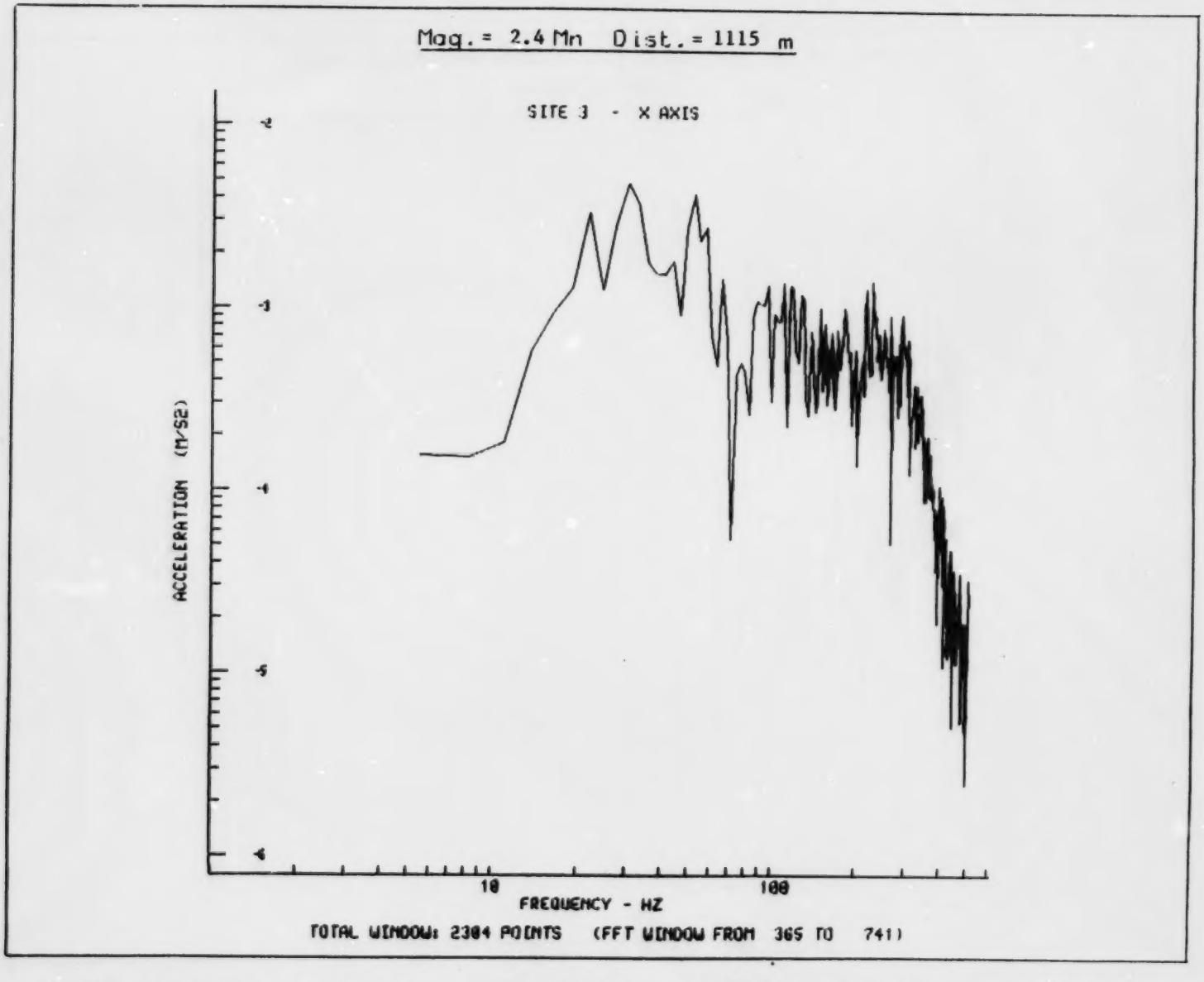

Fig. 2.6.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

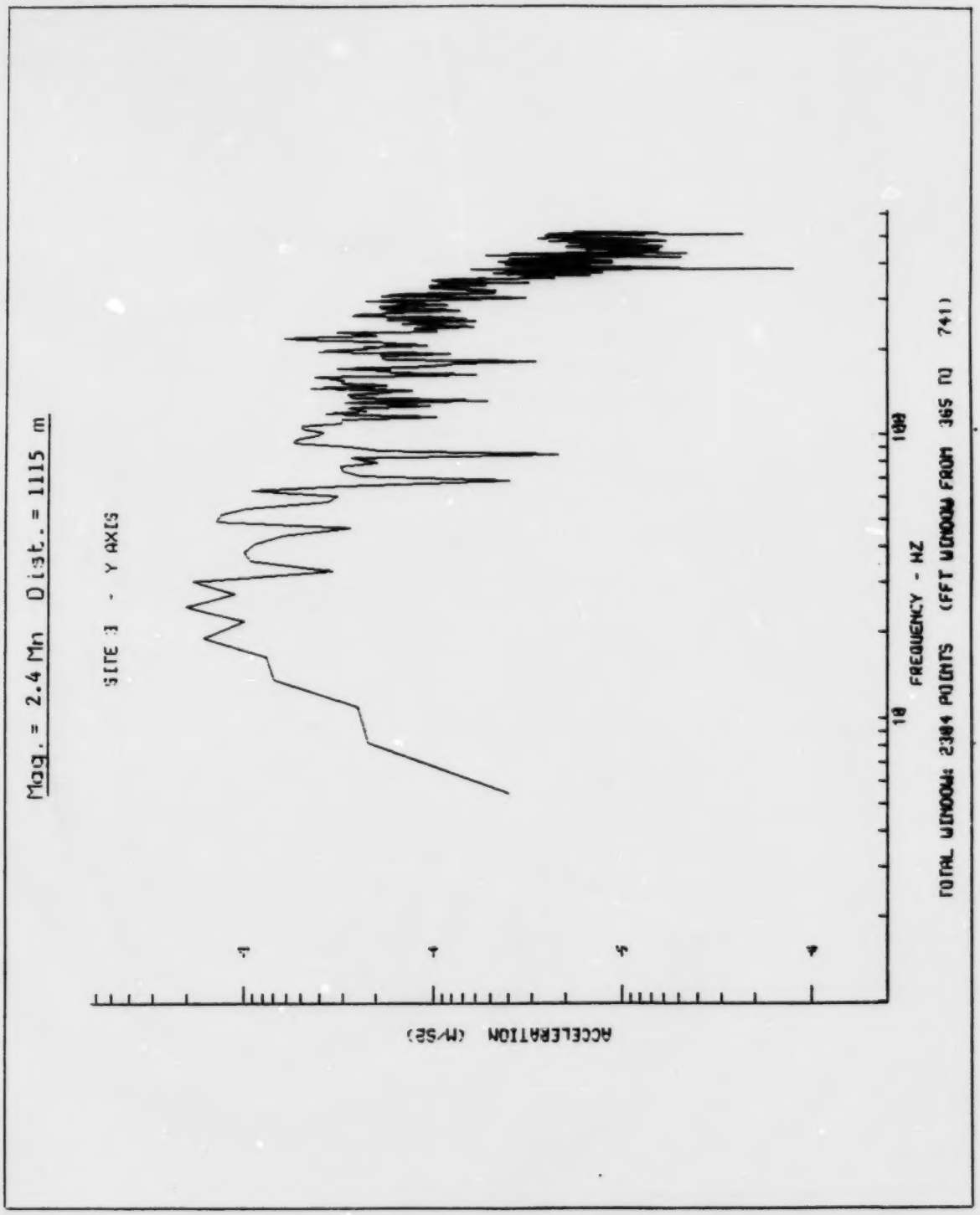

Fig. 2.6.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

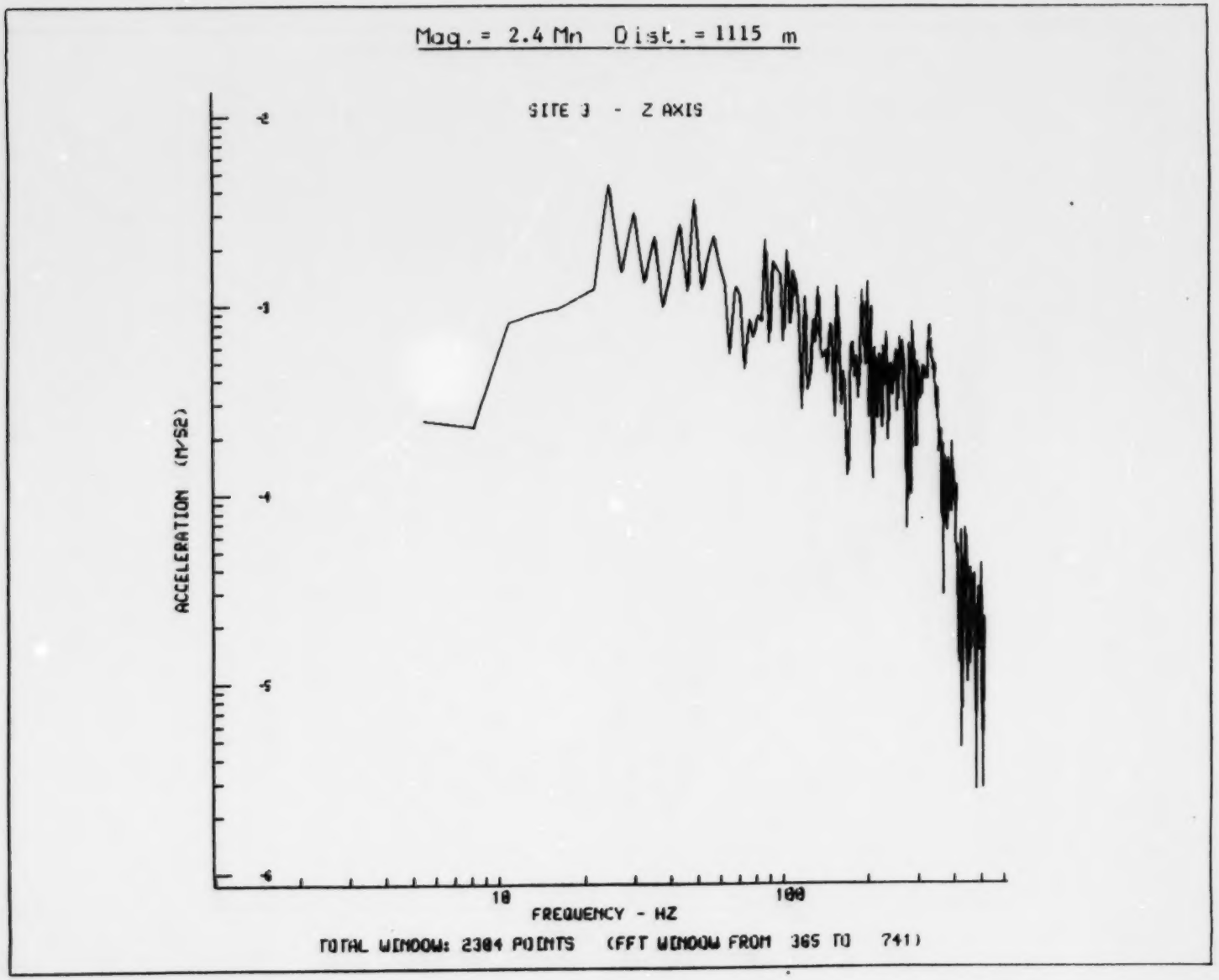

Fig. 2.6.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

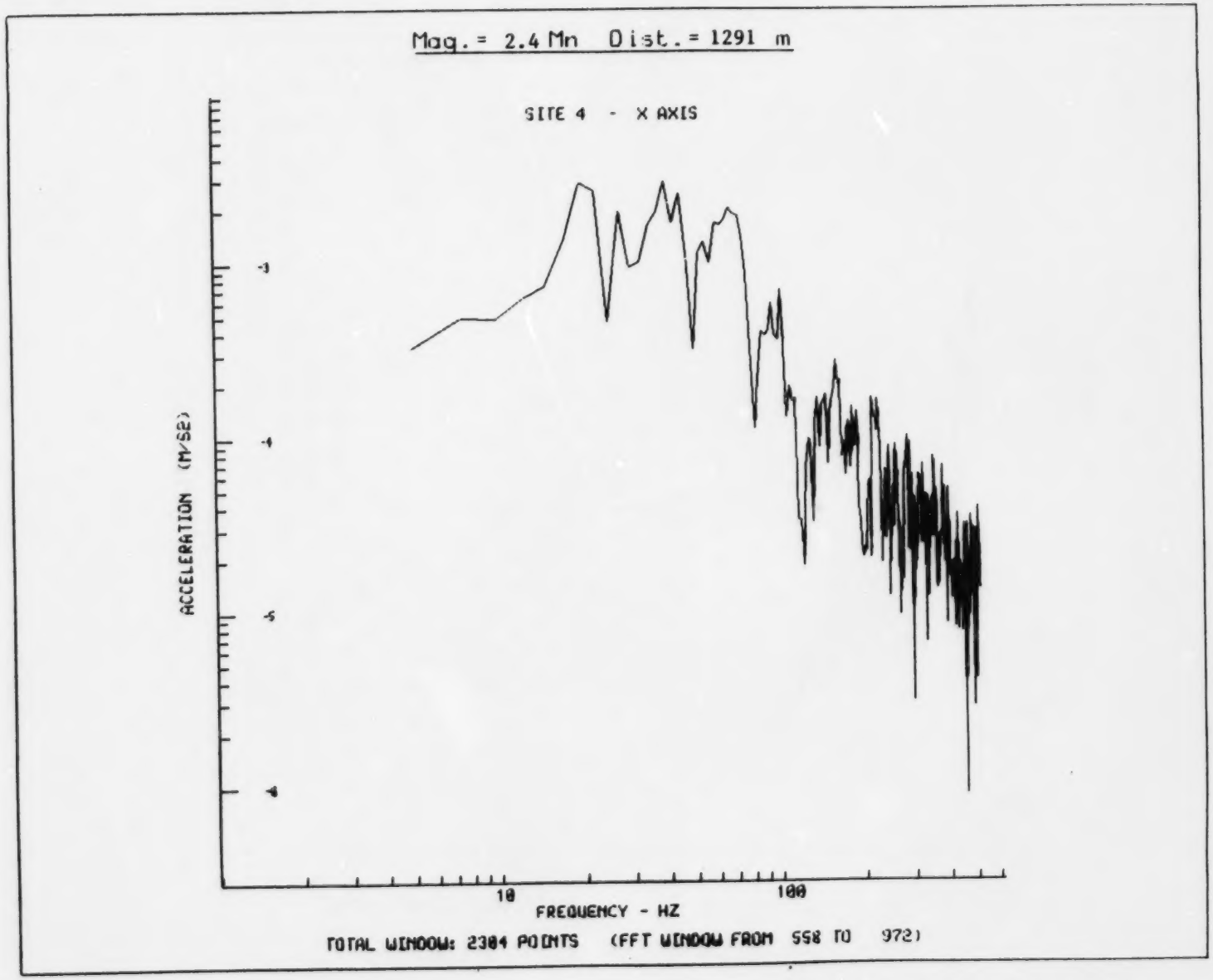

Fig. 2.7.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

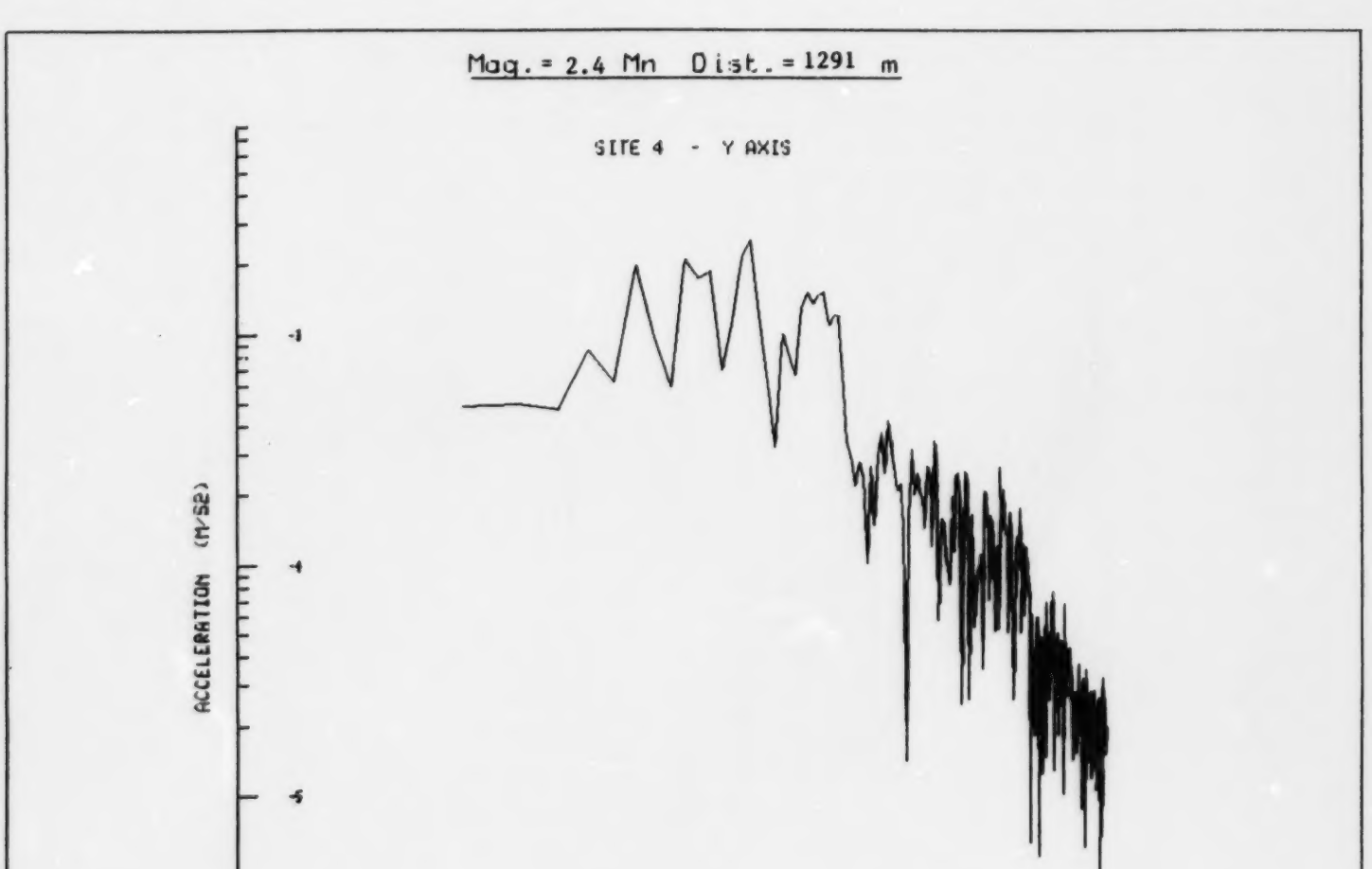

Fig. 2.7.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

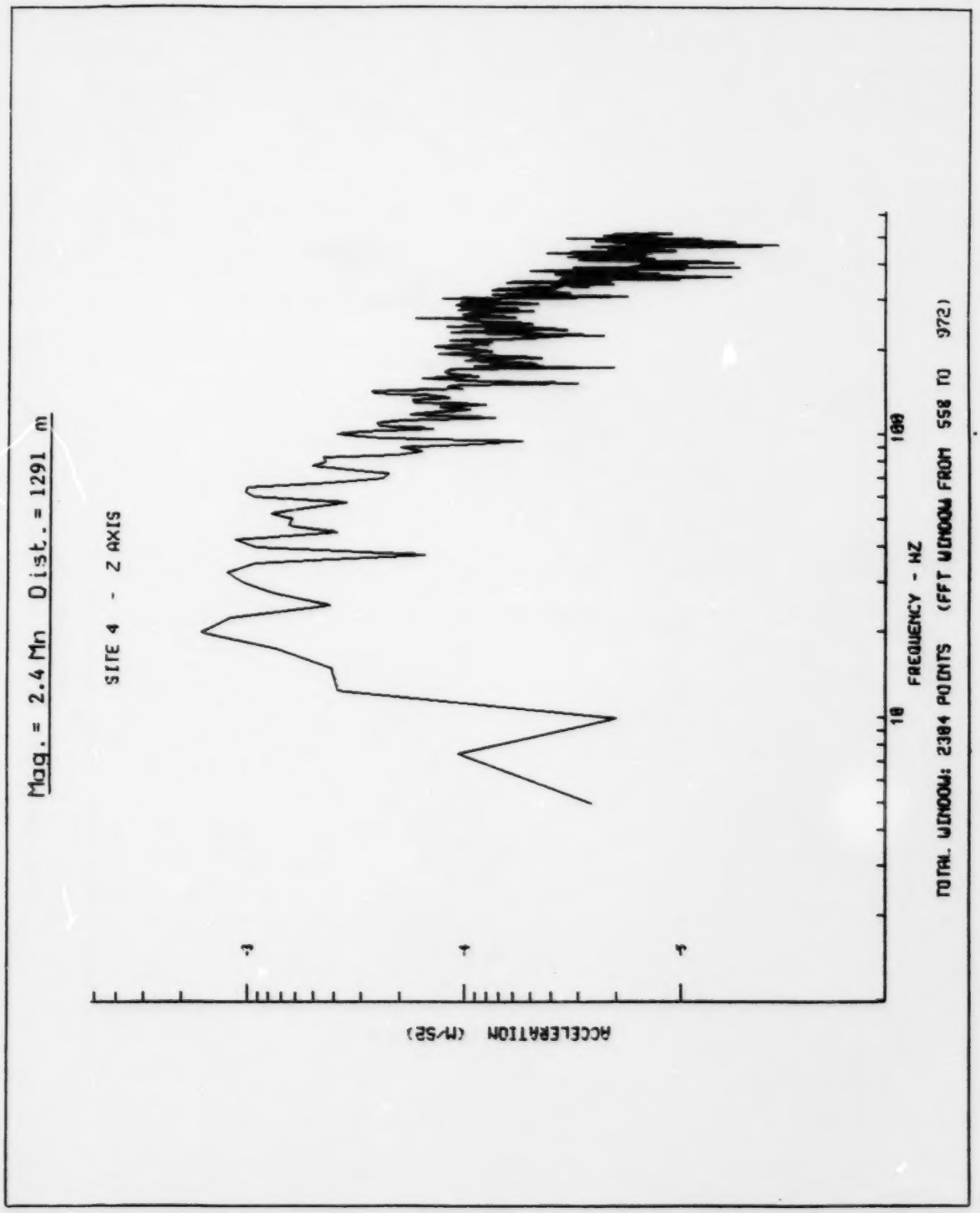

Fig. 2.7.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

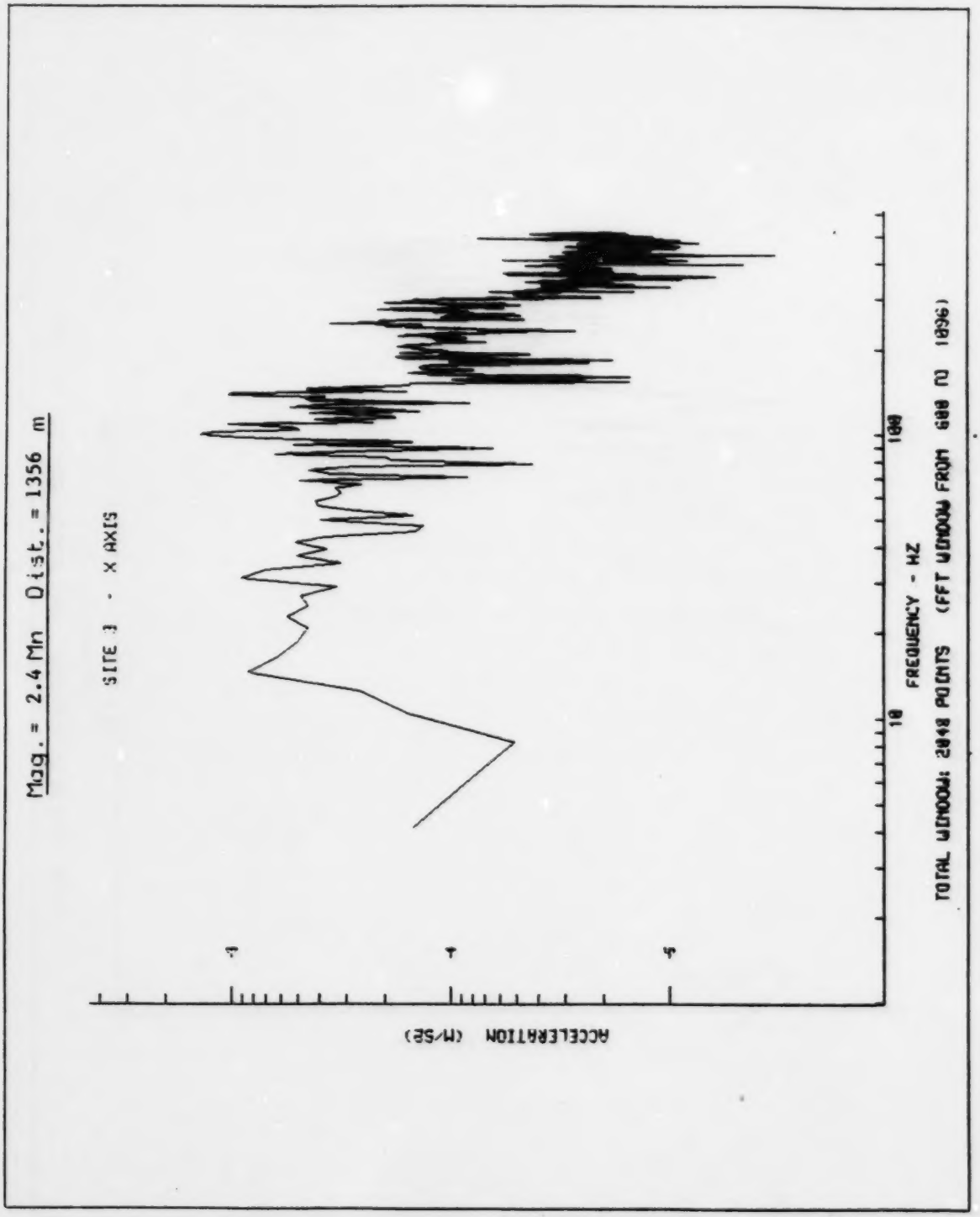

Fig. 2.8.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

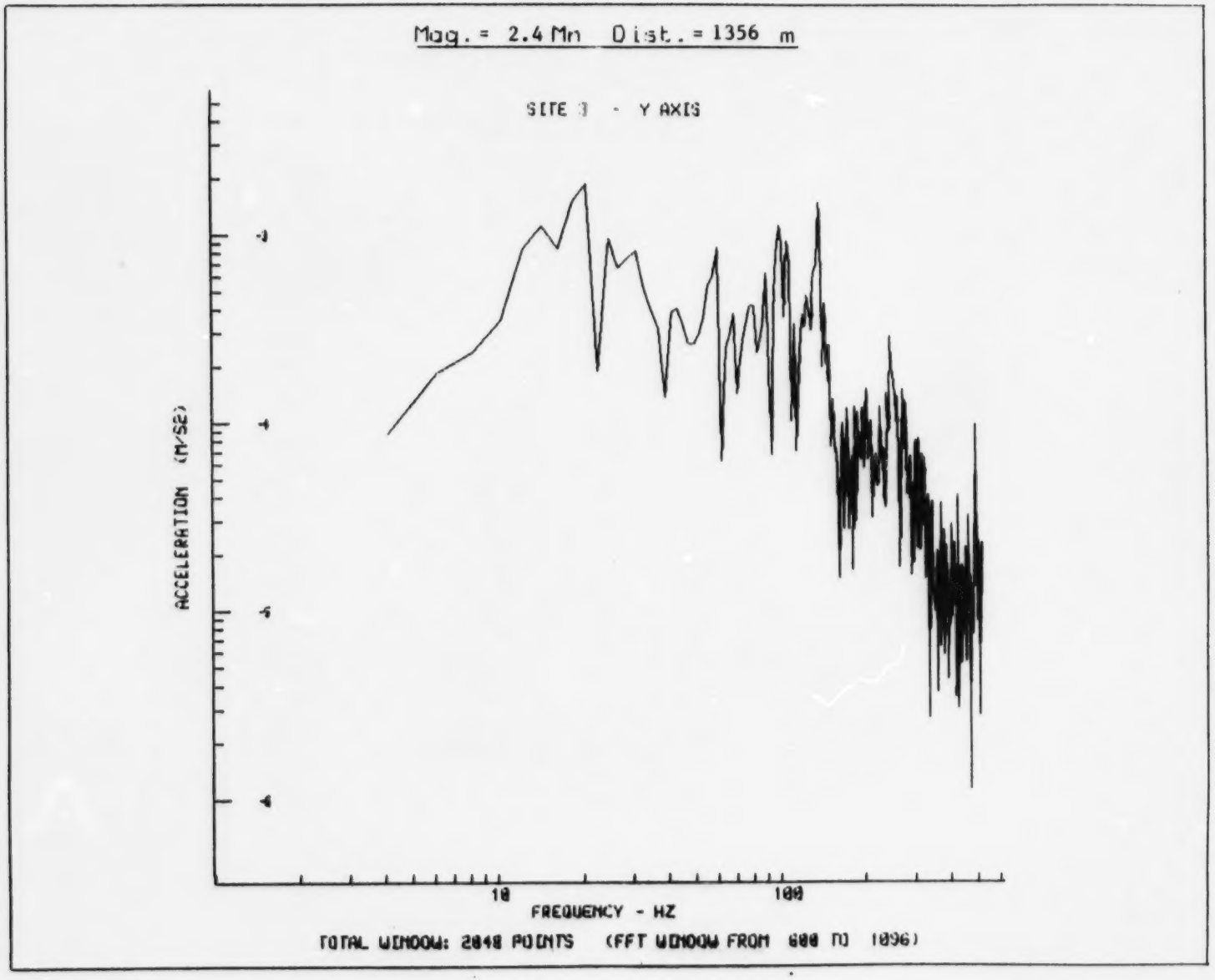
Mag. = 2.4 Mn Dist. = 1356 m
SITE 3 - Y AXIS
ACCELERATION (M/S2)
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2048 POINTS (FFT WINDOW FROM 600 TO 1096)

Fig. 2.8.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

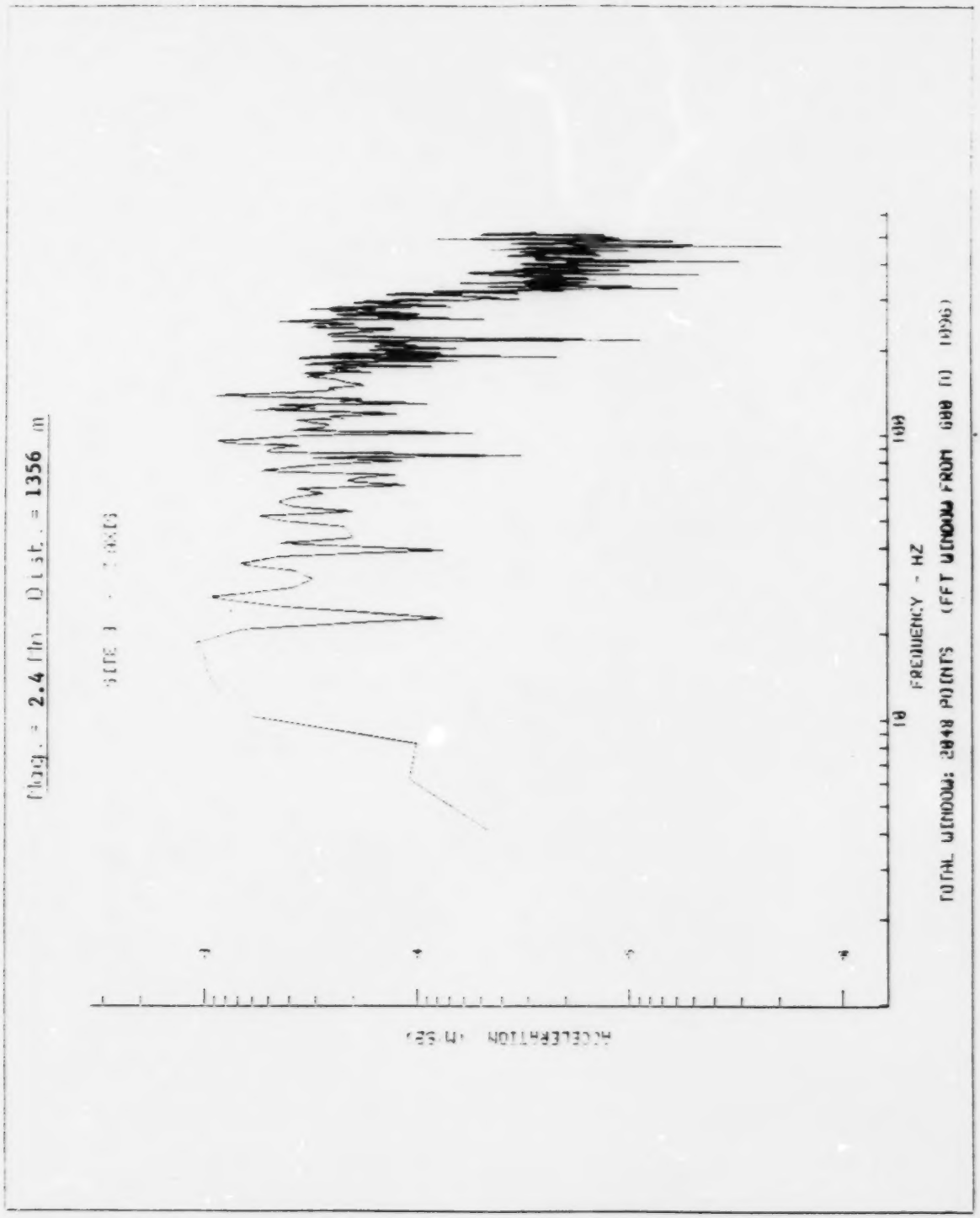

Fig. 2.8.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

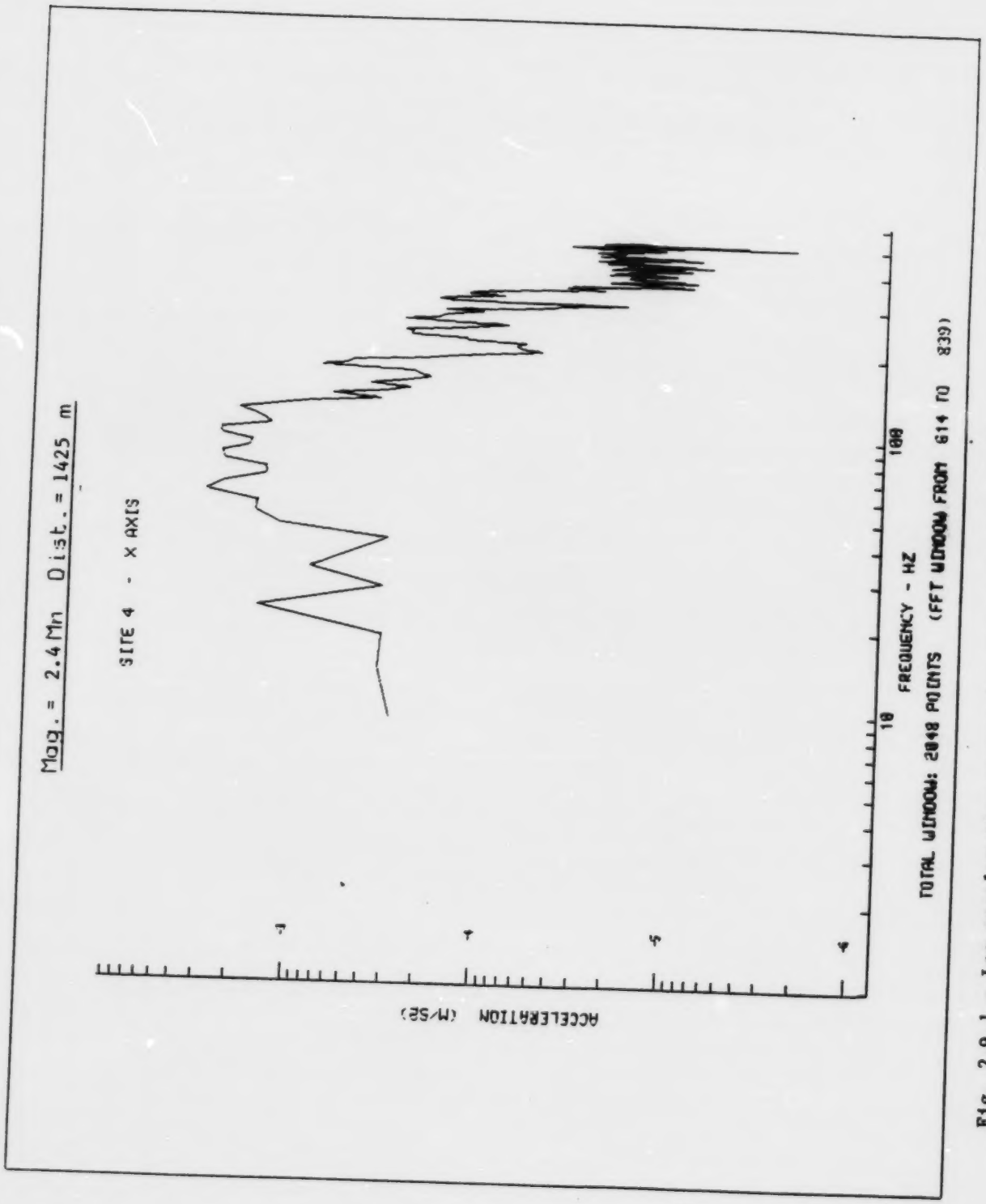

Fig. 2.9.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

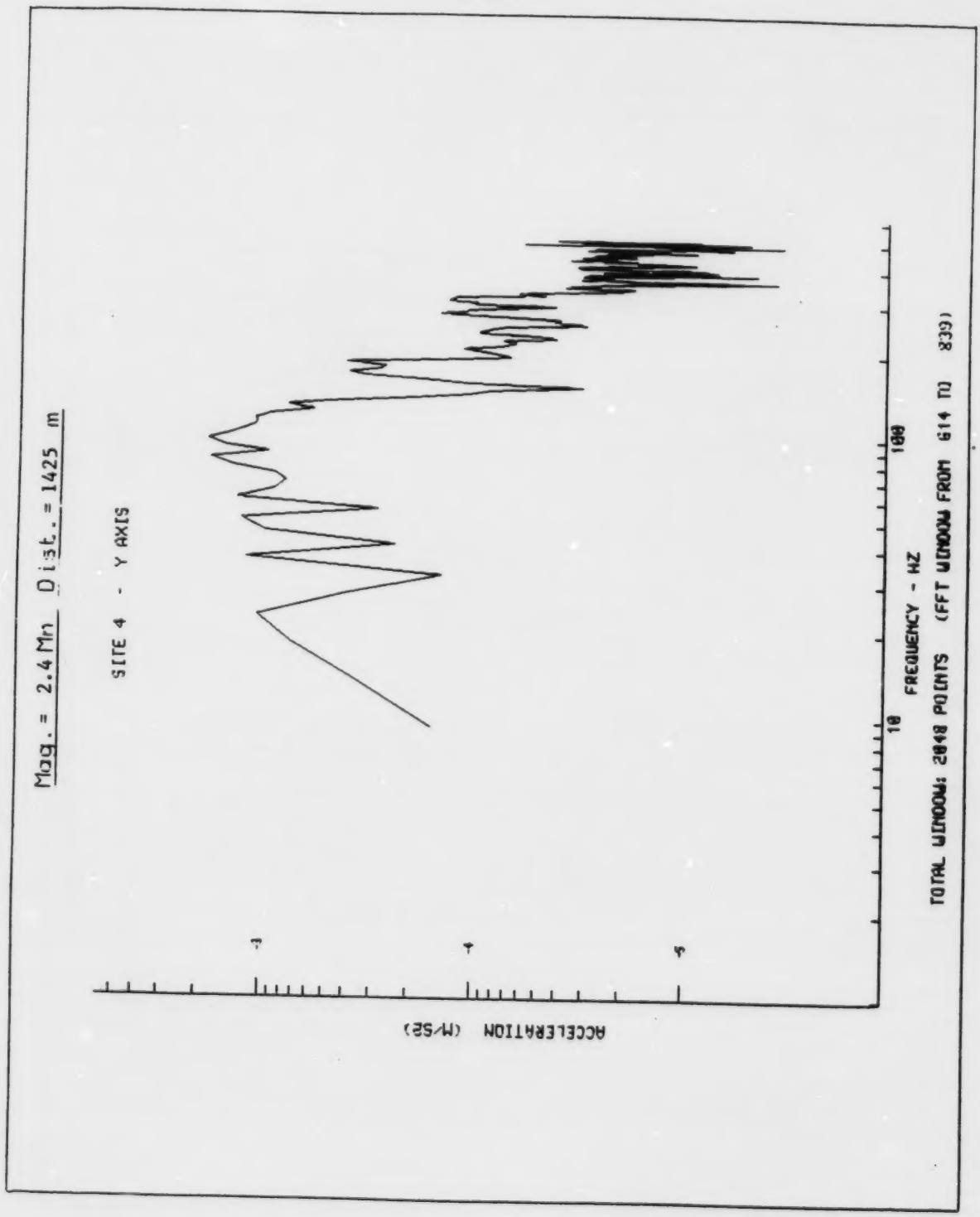

Fig. 2.9.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

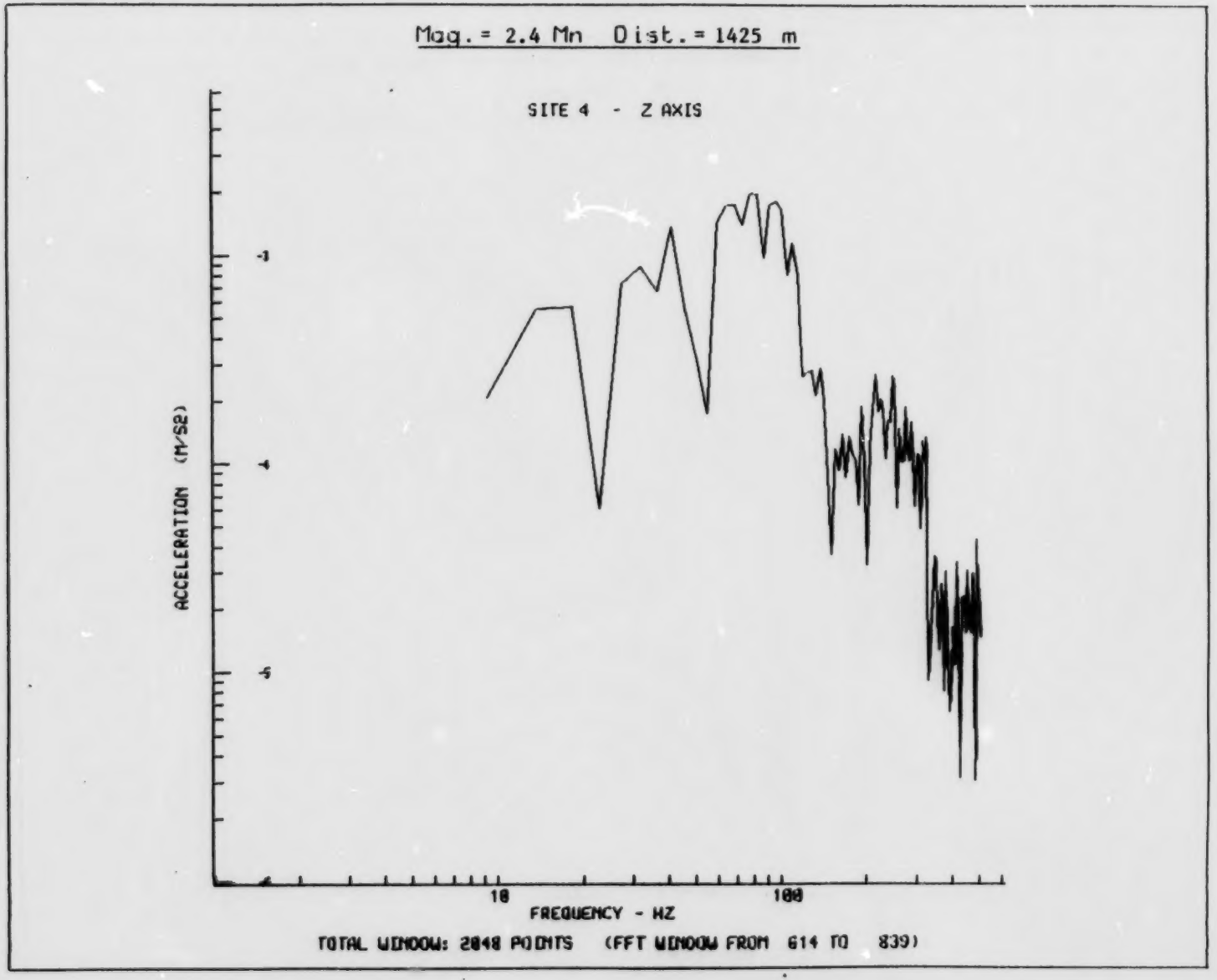

Fig. 2.9.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

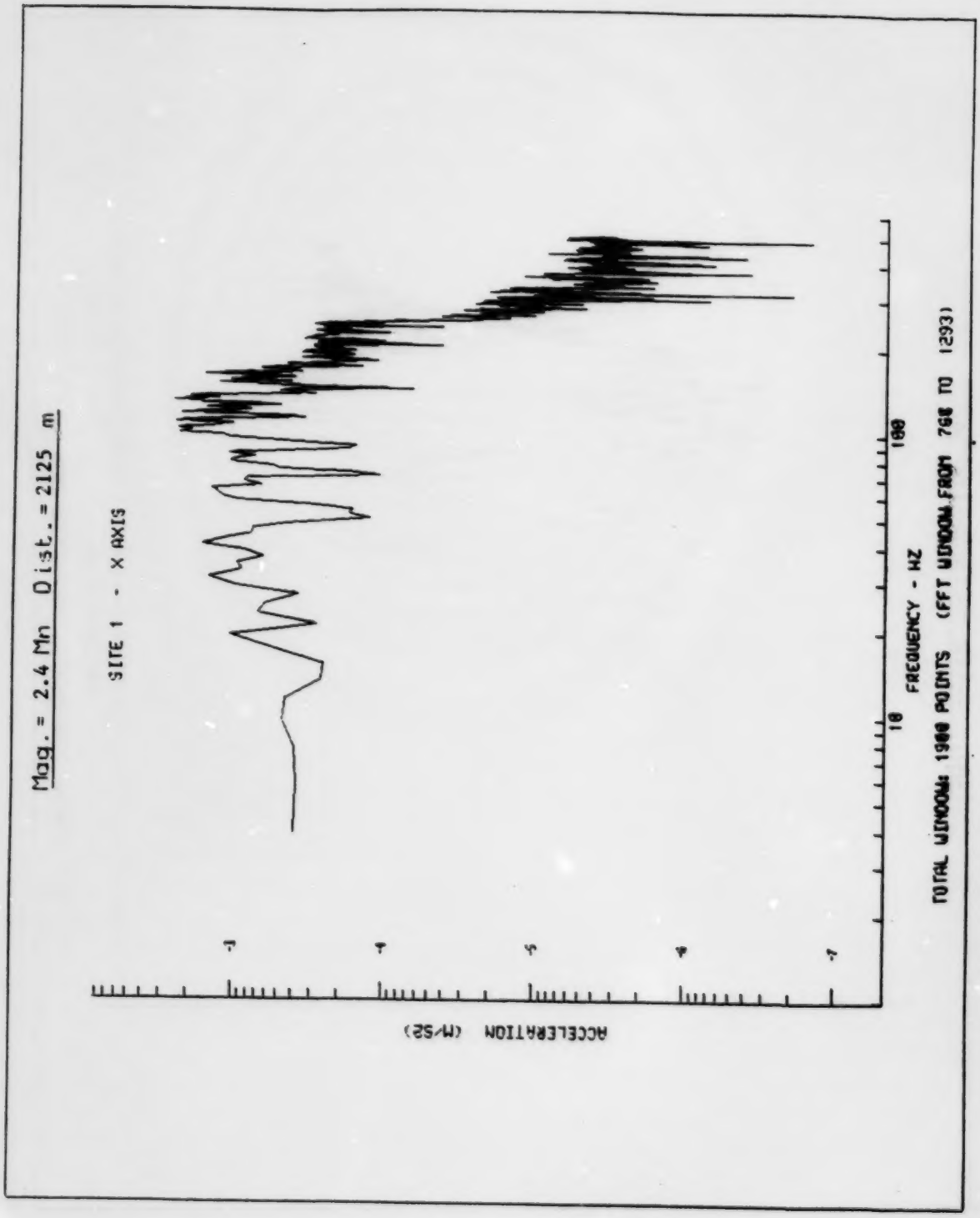

Fig. 2.10.1 - Log acceleration versus log frequency for east/west axis at 2.4 magnitude.

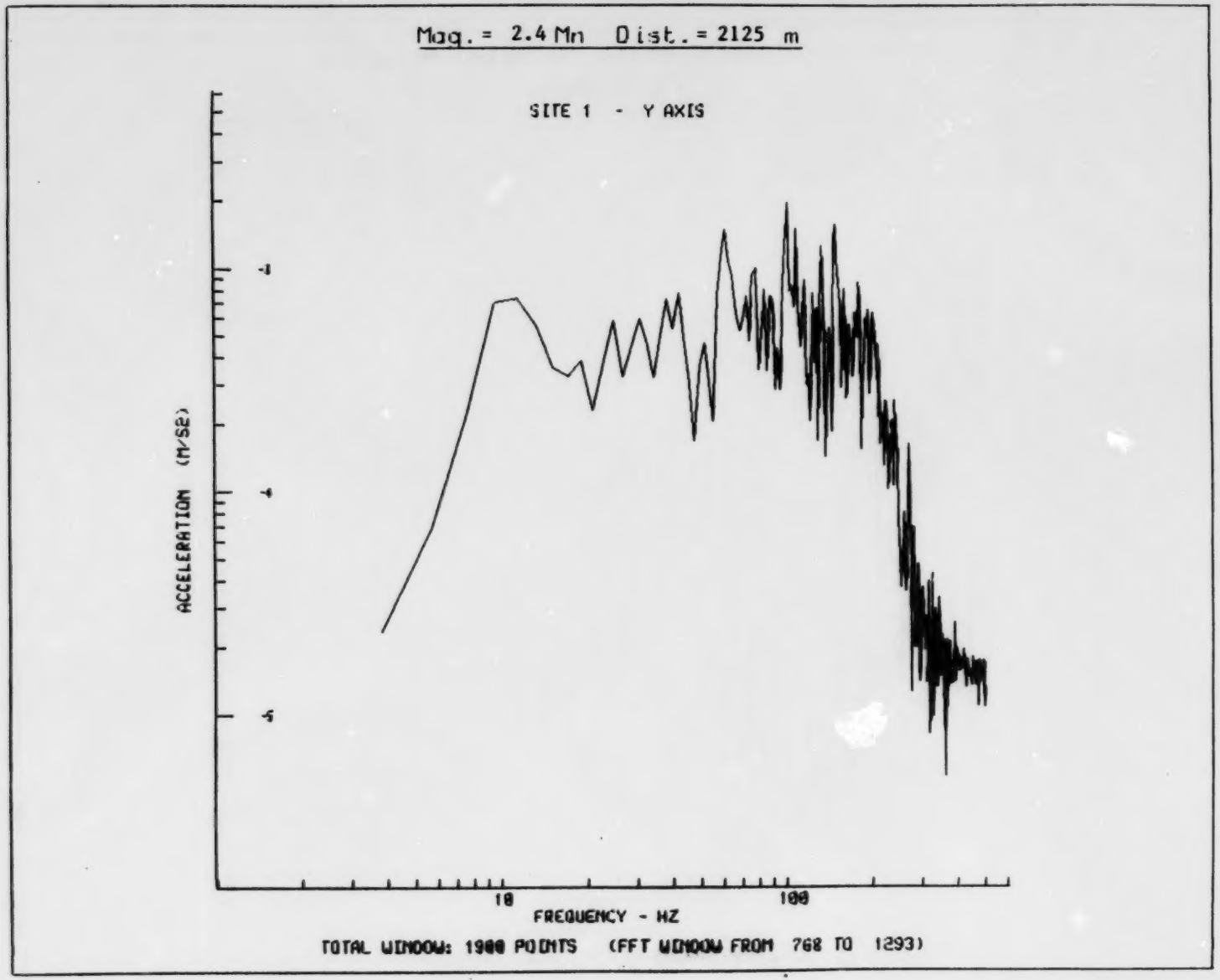

Fig. 2.10.2 - Log acceleration versus log frequency for north/south axis at 2.4 magnitude.

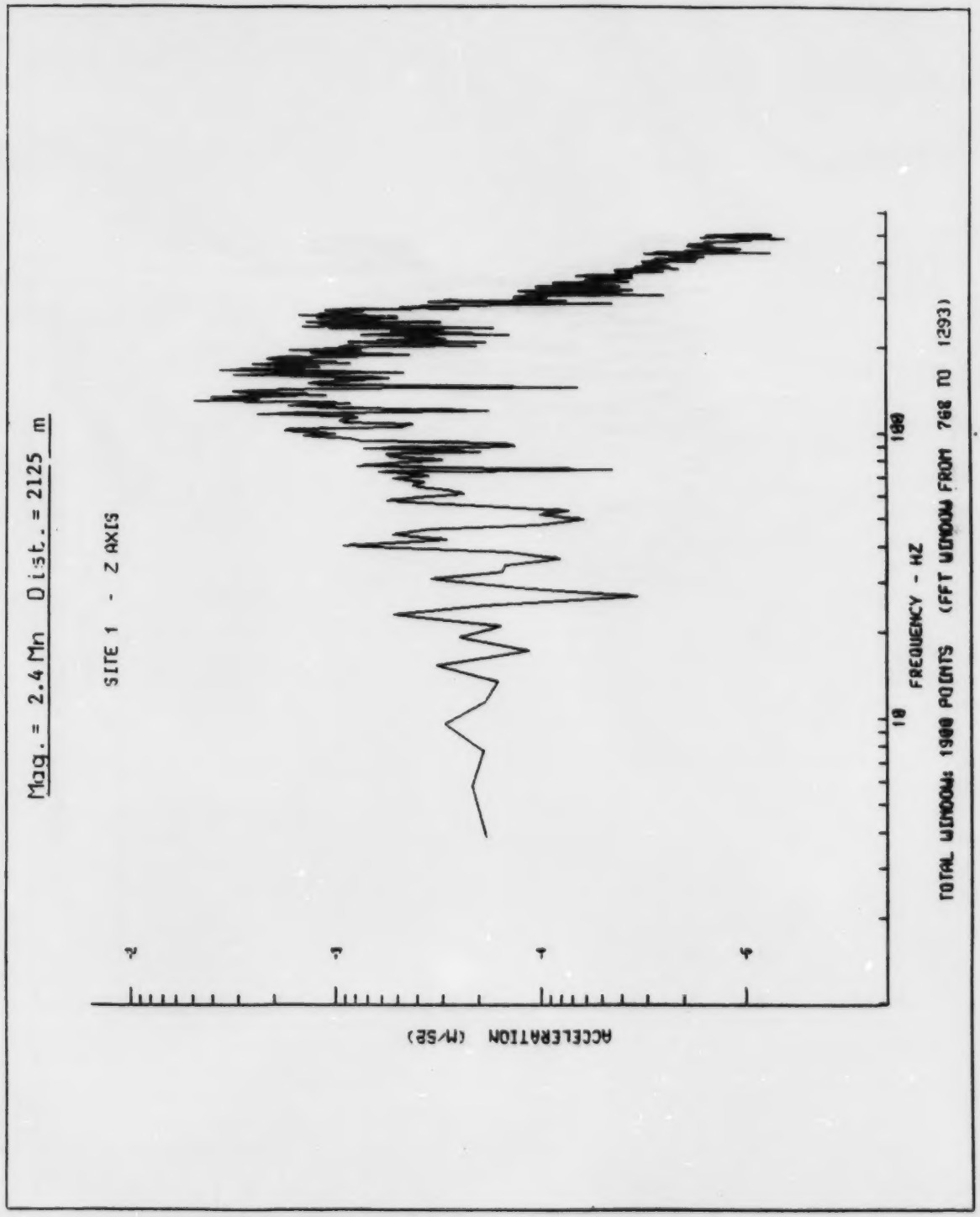

Fig. 2.10.3 - Log acceleration versus log frequency for elevation at 2.4 magnitude.

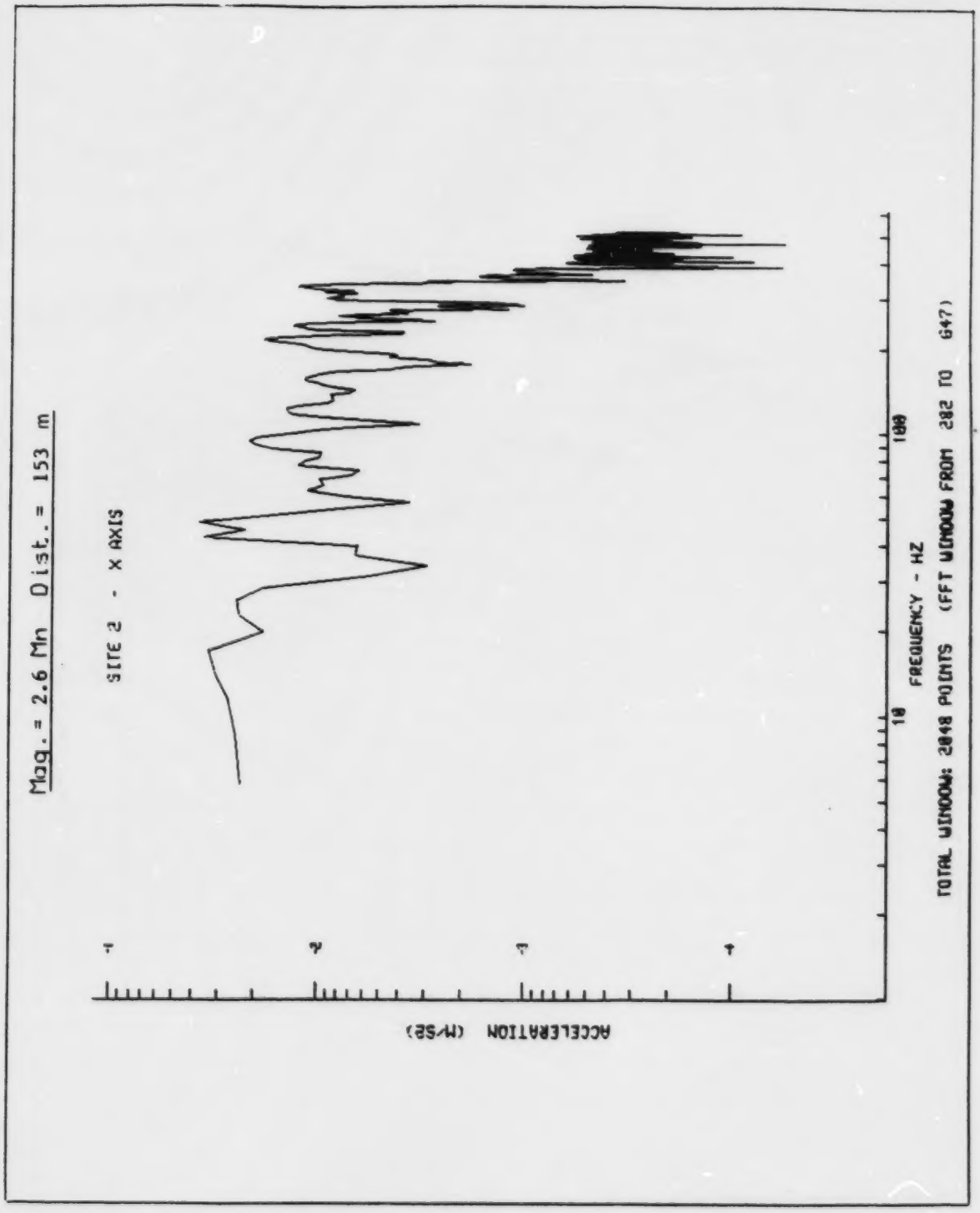

Fig. 3.1.1 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

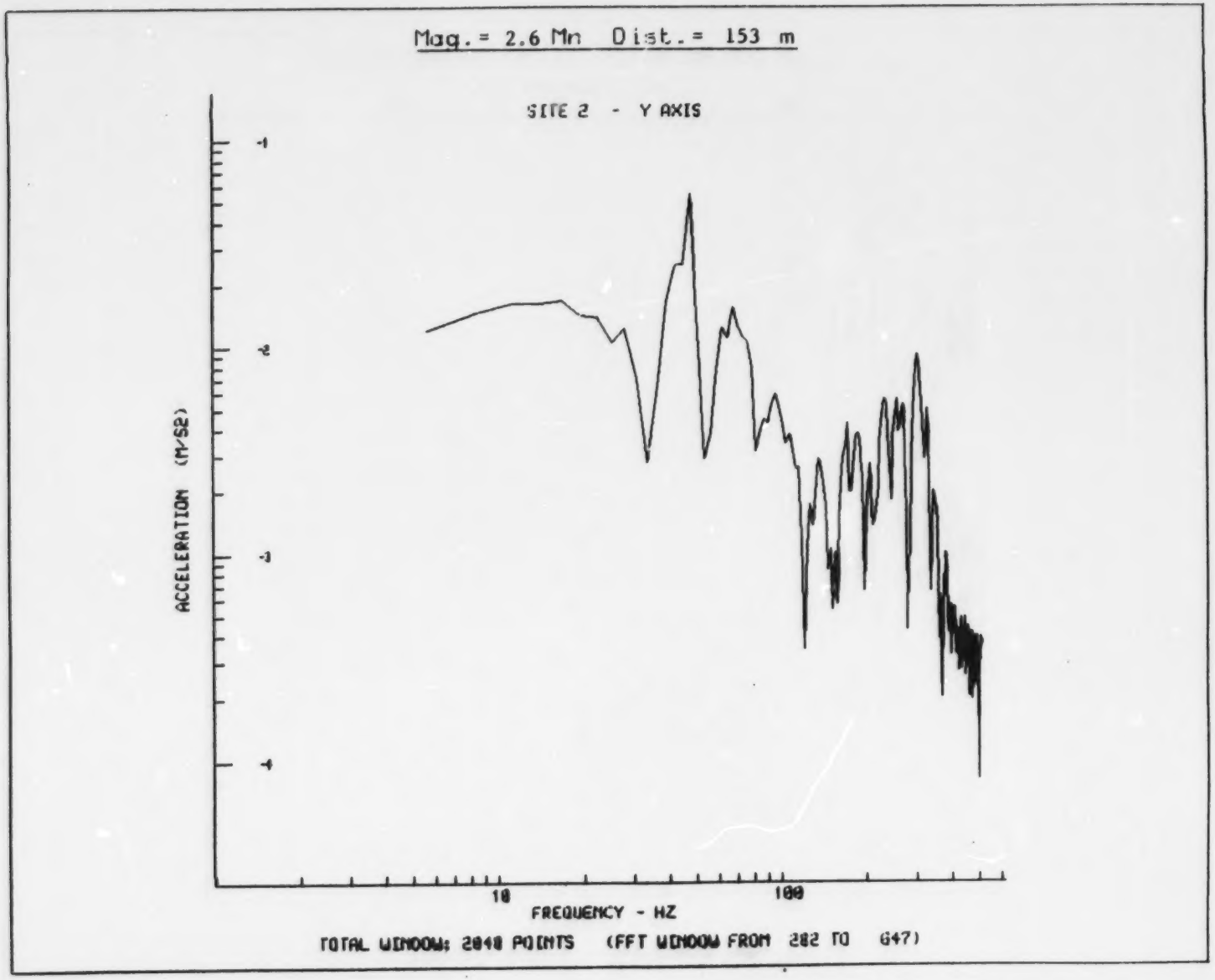

Fig. 3.1.2 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

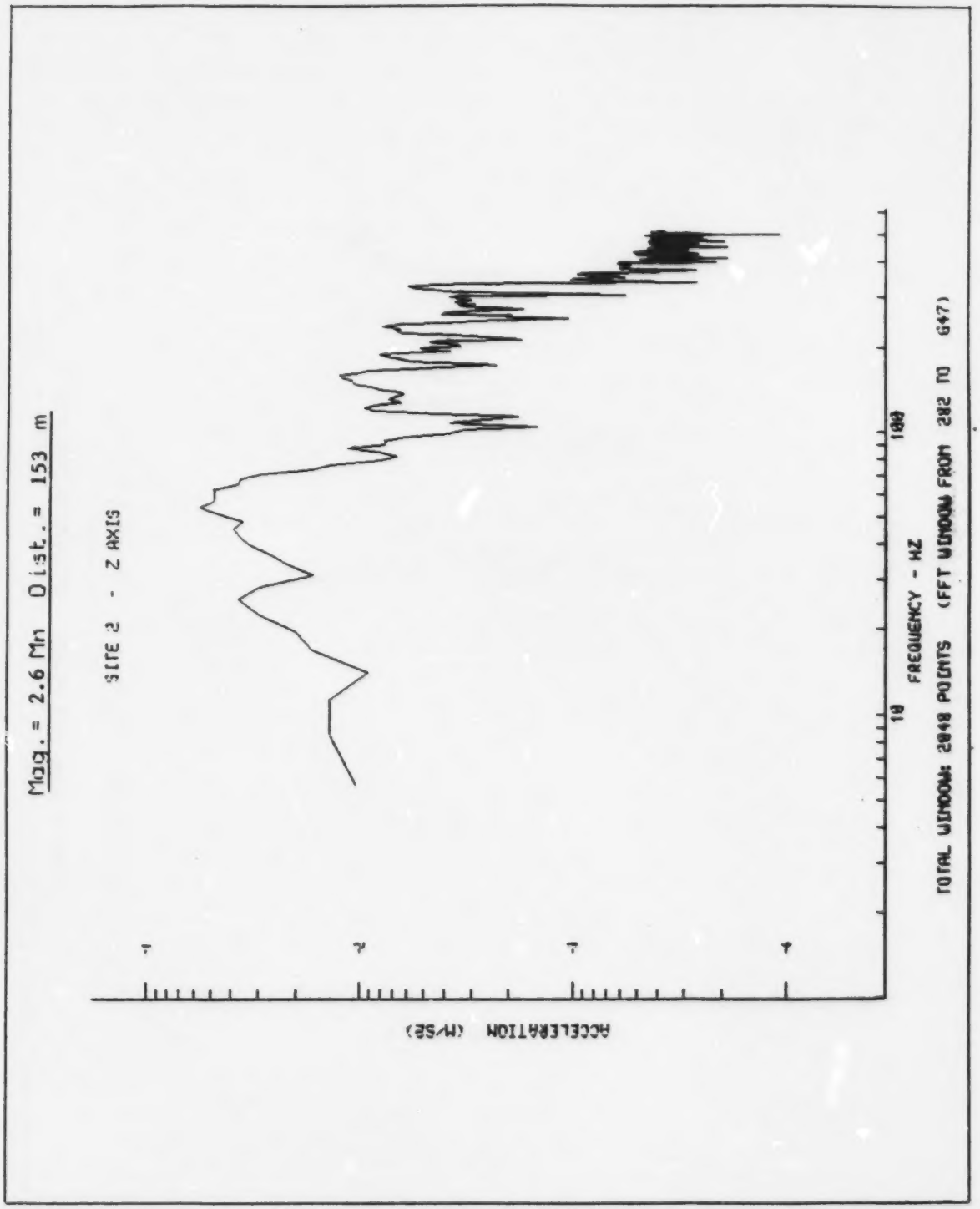

Fig. 3.1.3 Log acceleration versus log frequency for elevation at 2.6 magnitude.

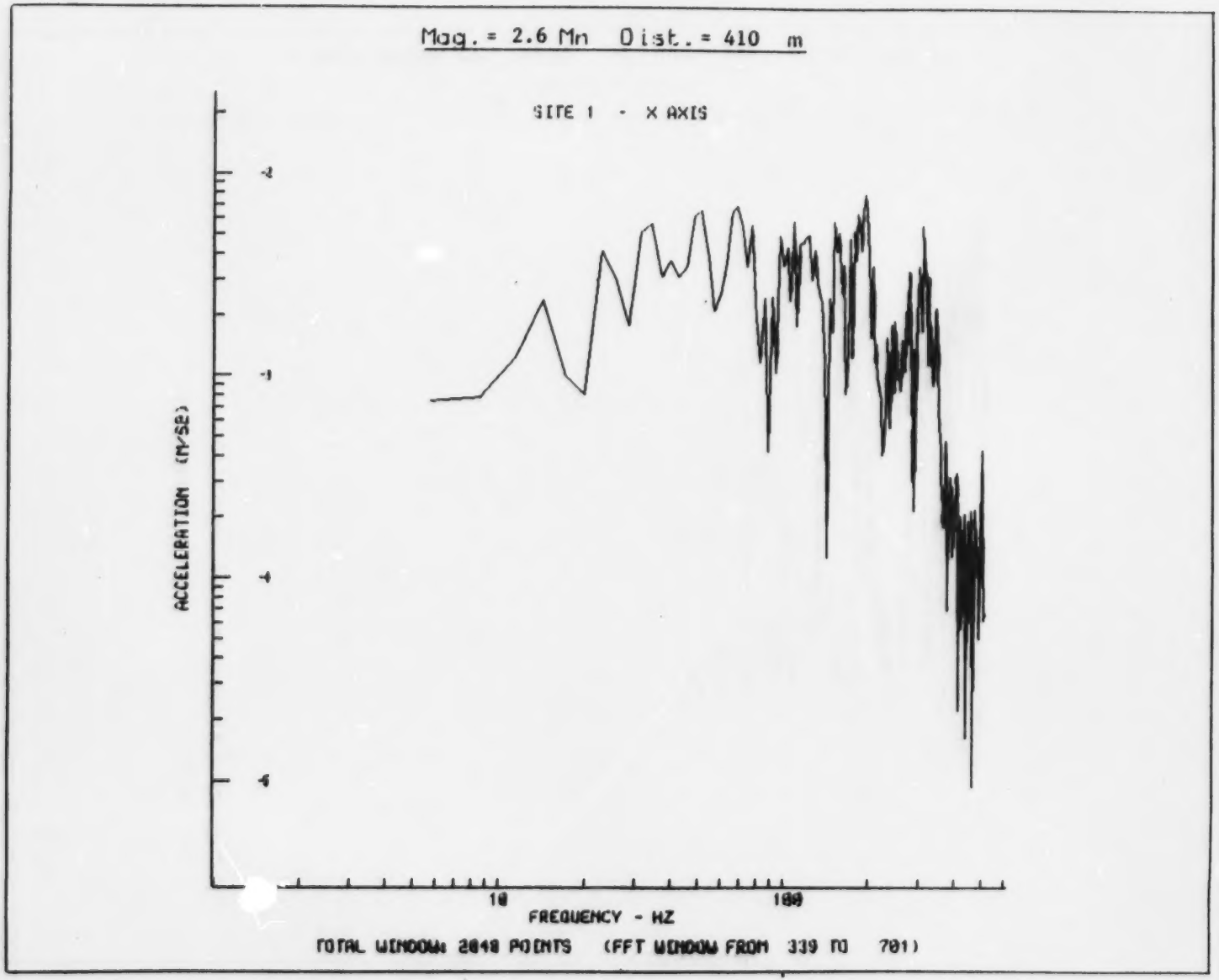

Fig. 3.2.1 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

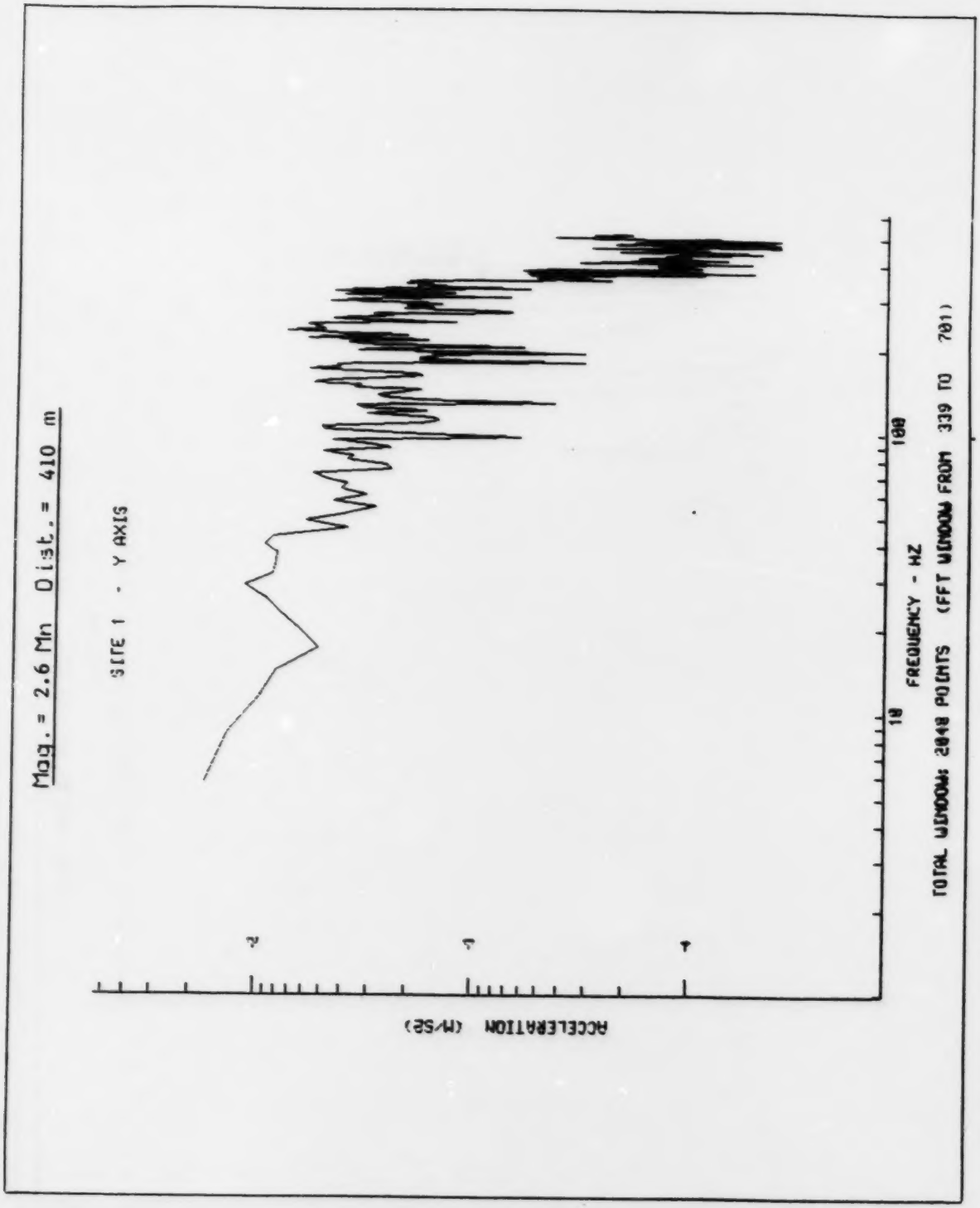

Fig. 3.2.2 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

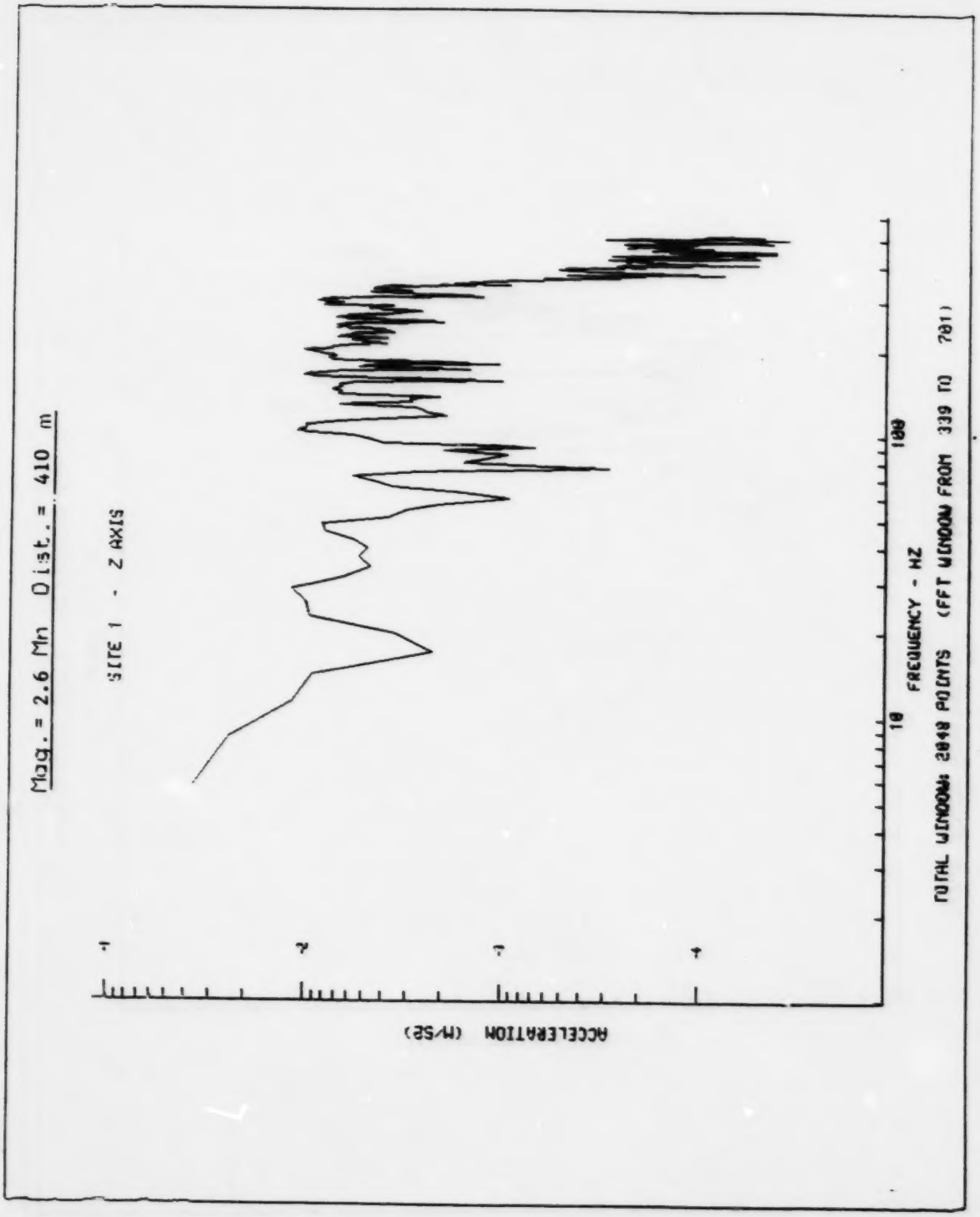

Fig. 3.2.3 - Log acceleration versus log frequency for elevation at 2.6 magnitude.

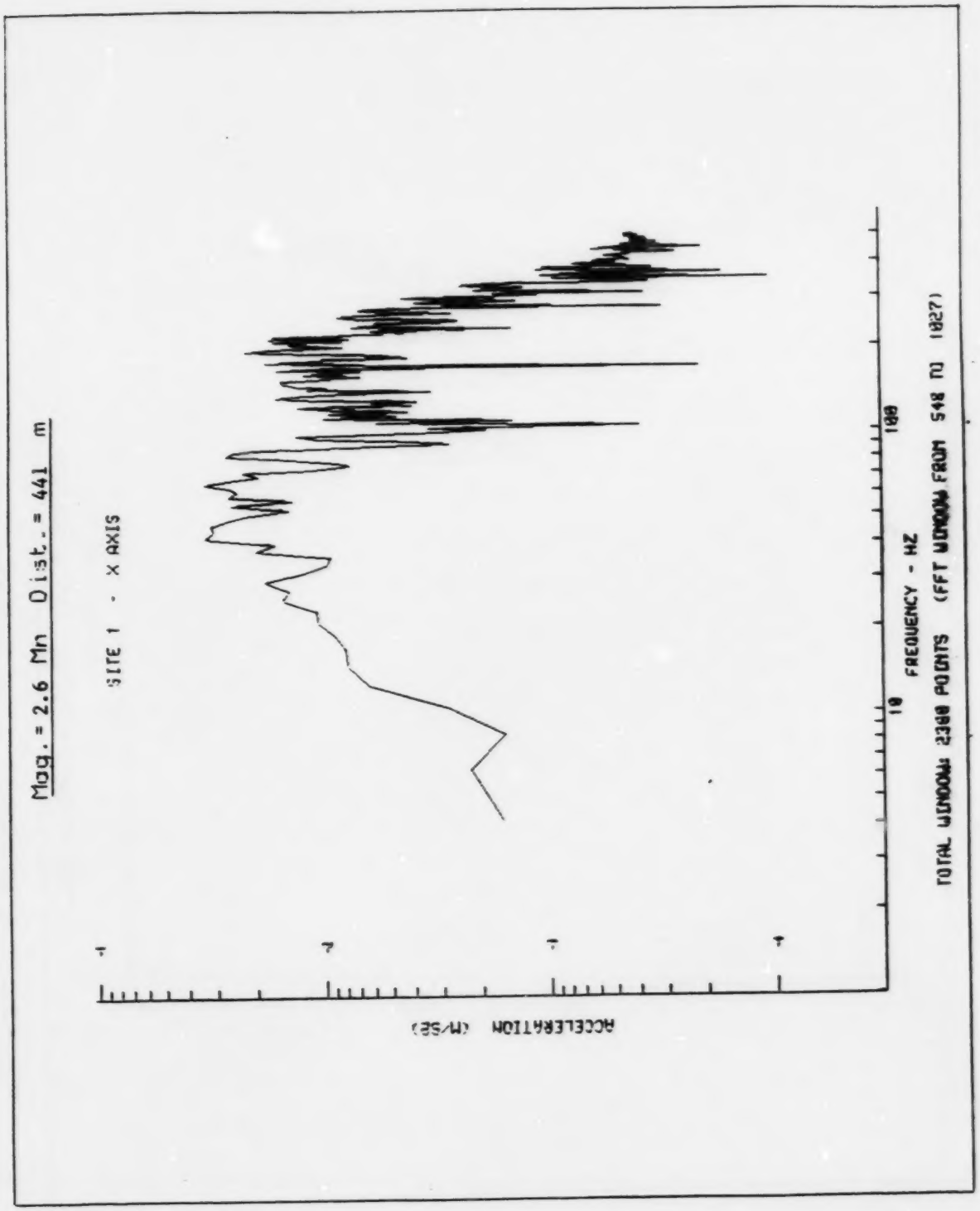

Fig. 3.3.1 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

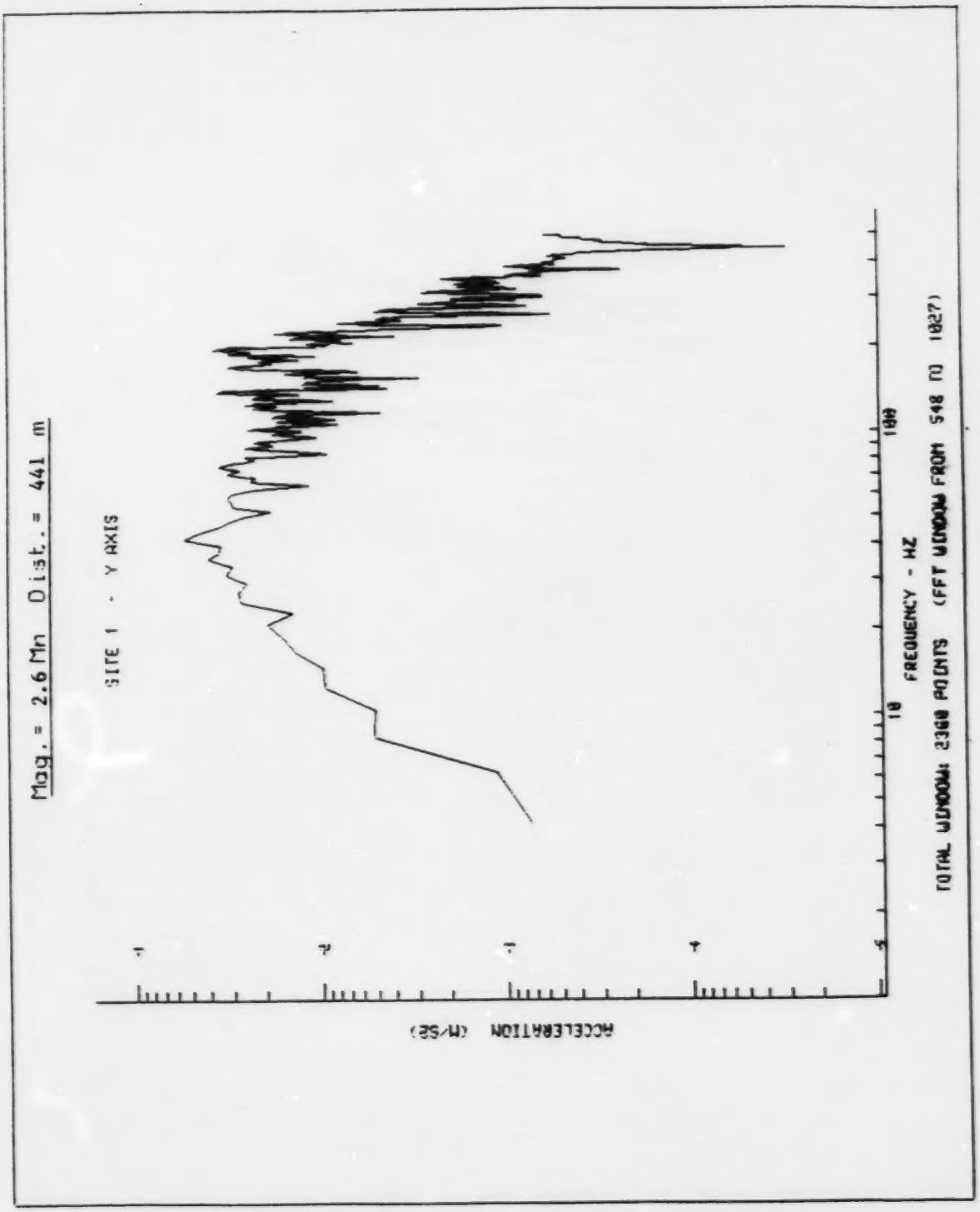

Fig. 3.3.2 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

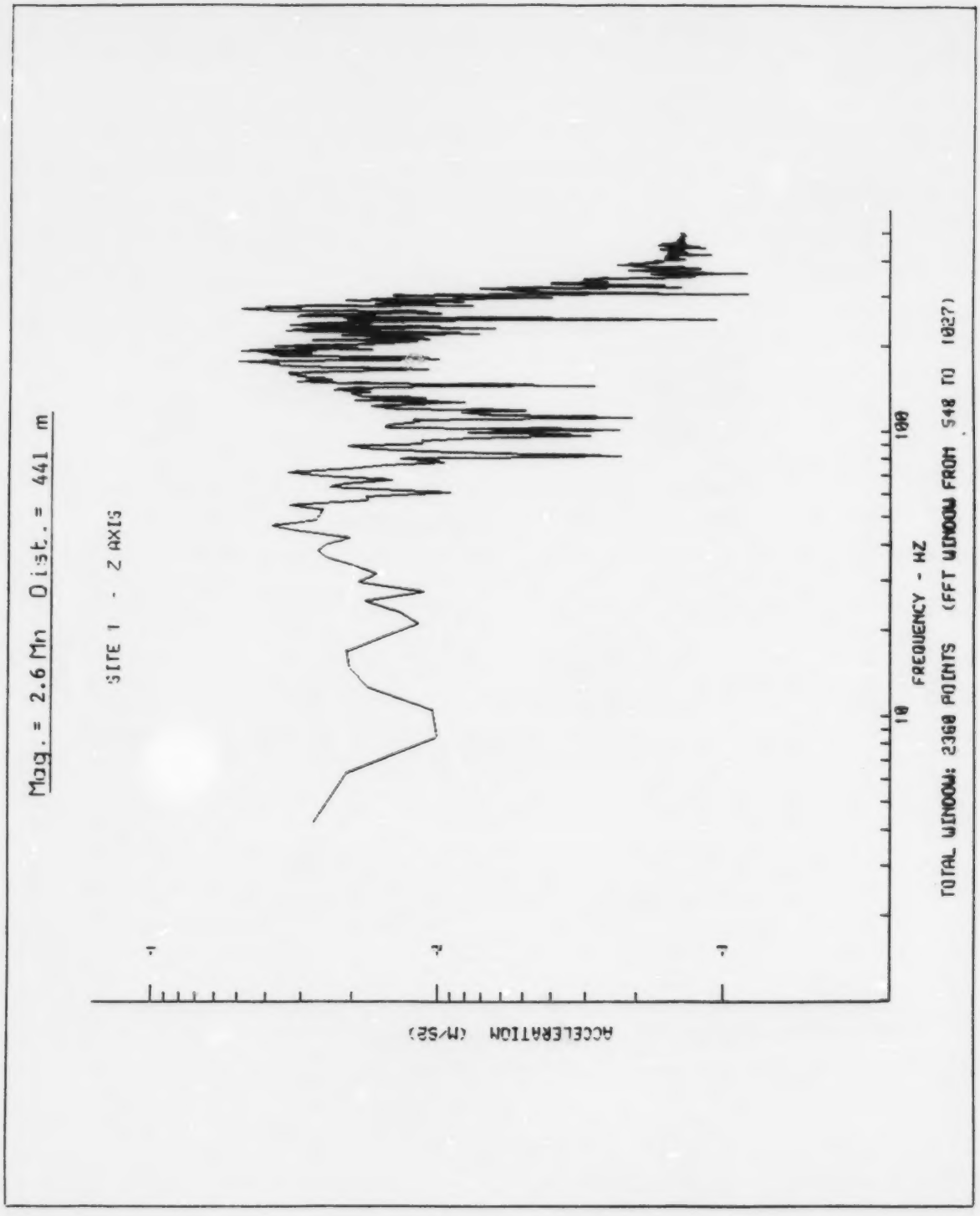

Fig. 3.3.3 - Log acceleration versus log frequency for elevation at 2.6 magnitude.

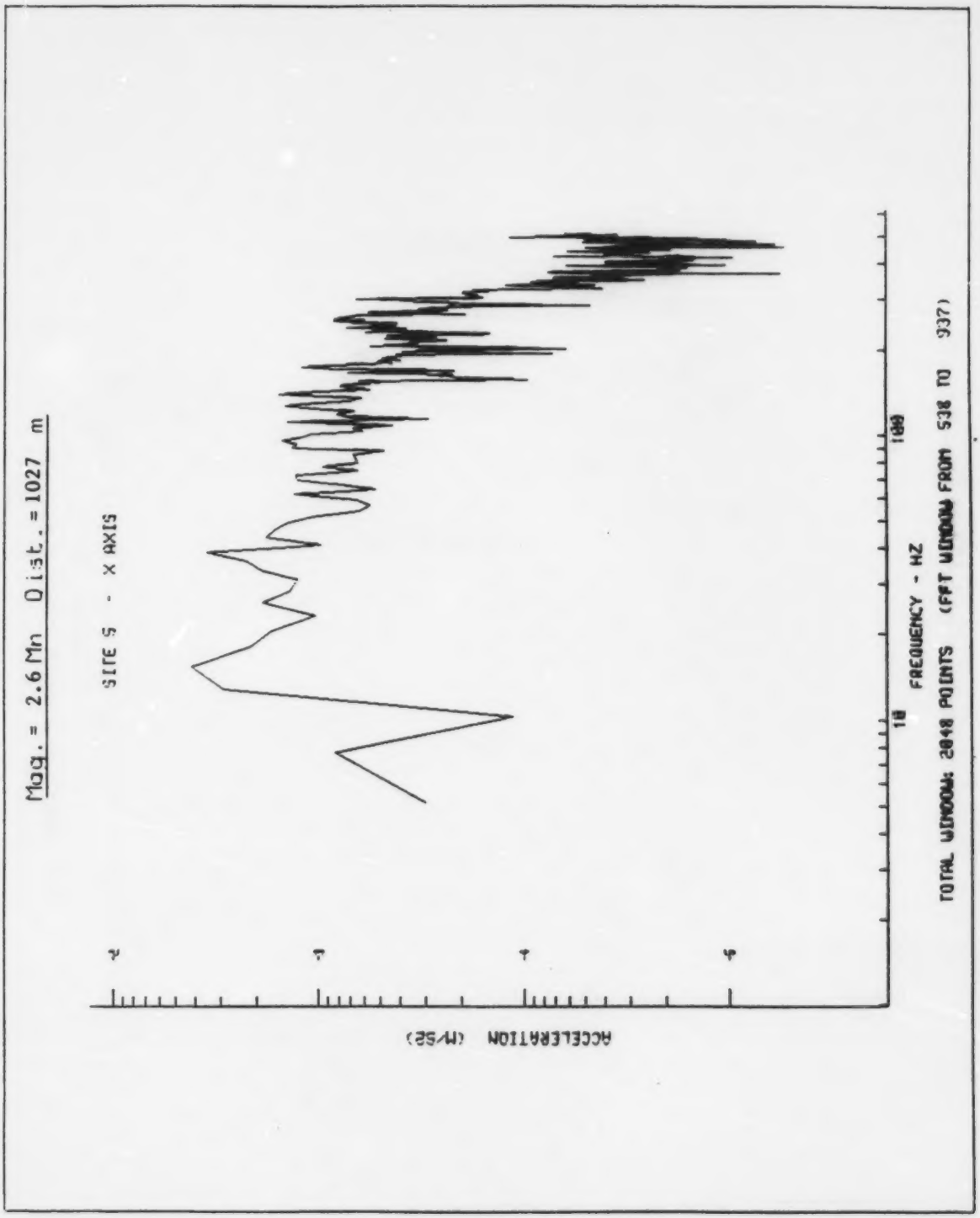

Fig. 3.4.1 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

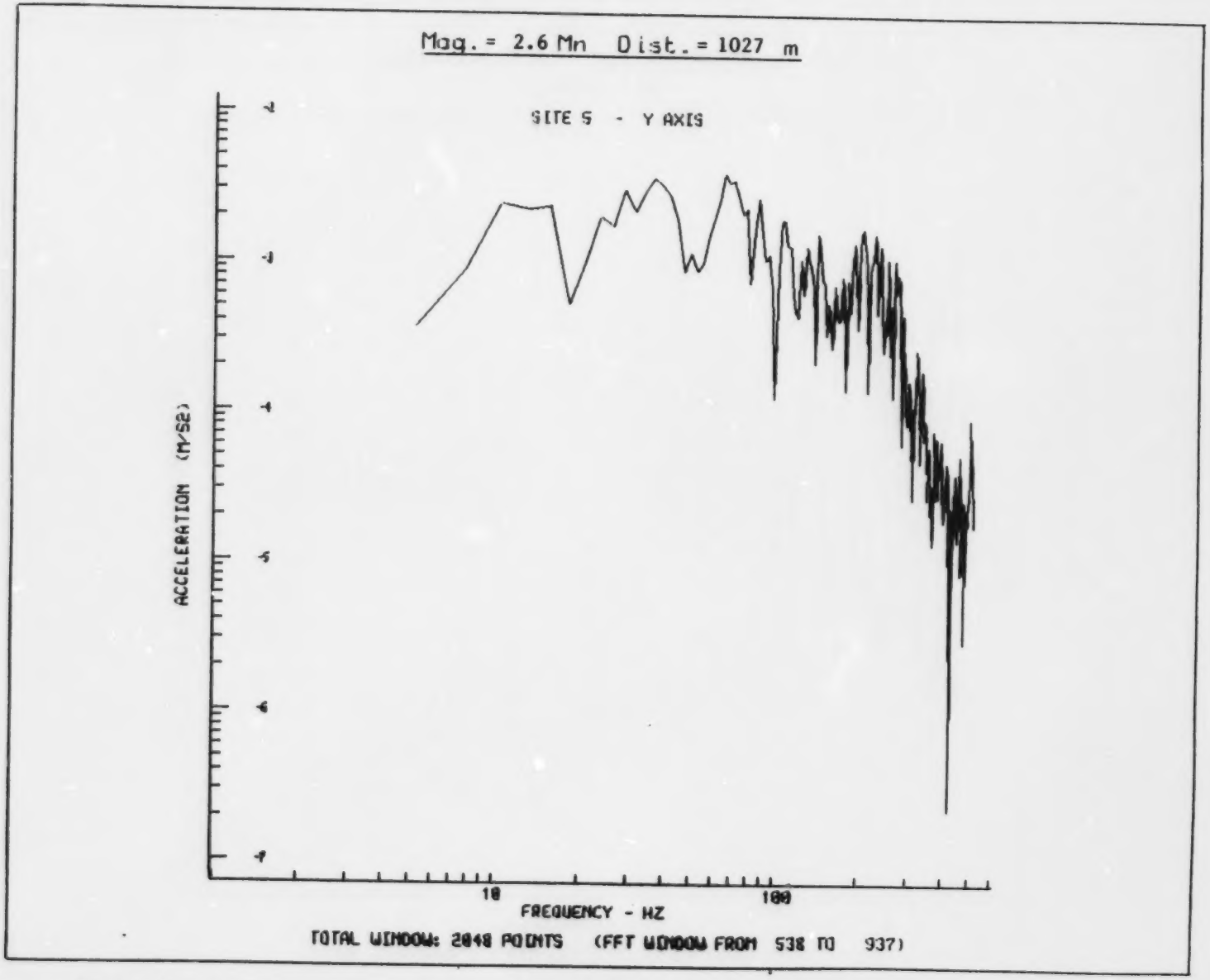

Fig. 3.4.2 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

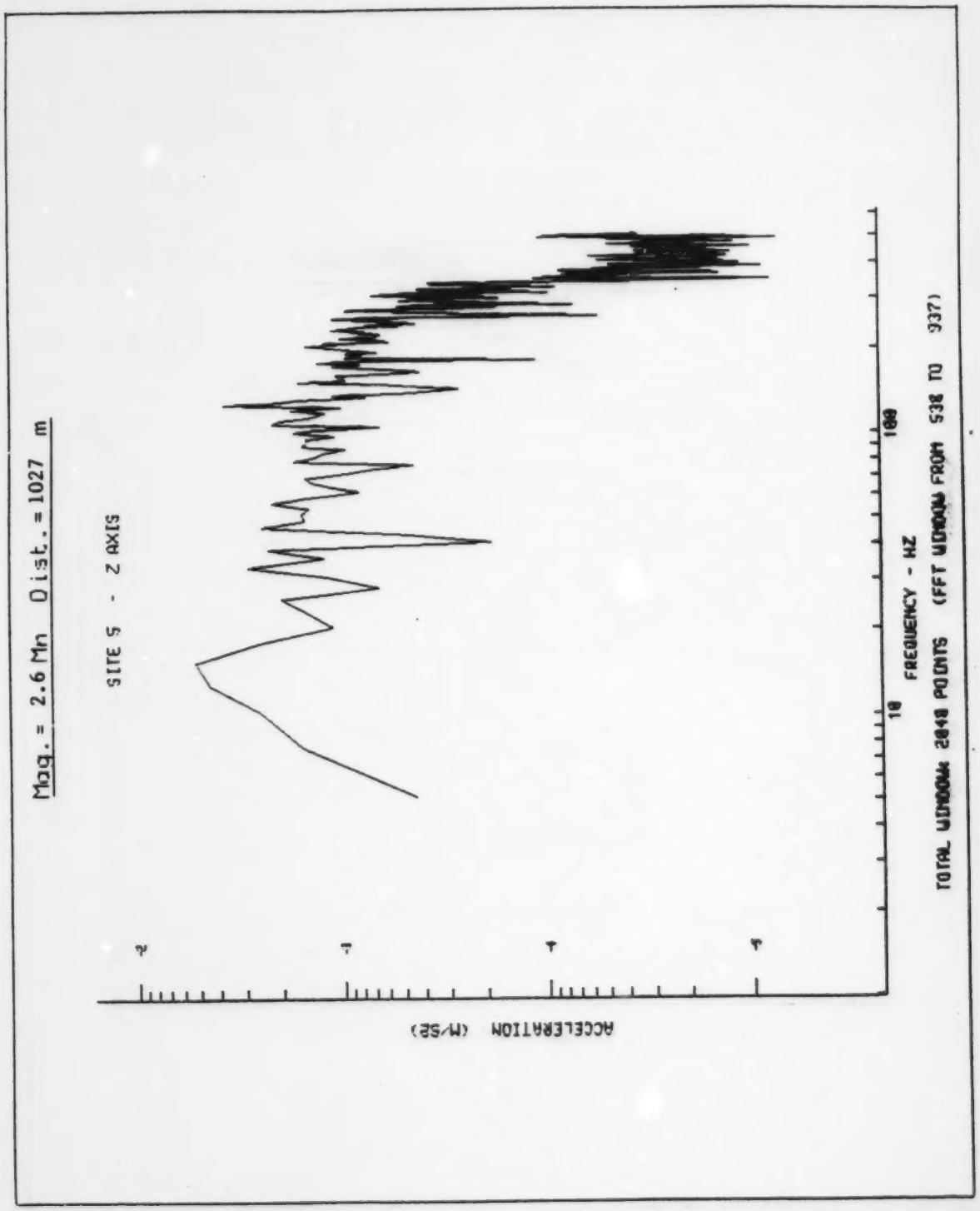

Fig. 3.4.3 - Log acceleration versus log frequency for elevation at 2.6 magnitude.

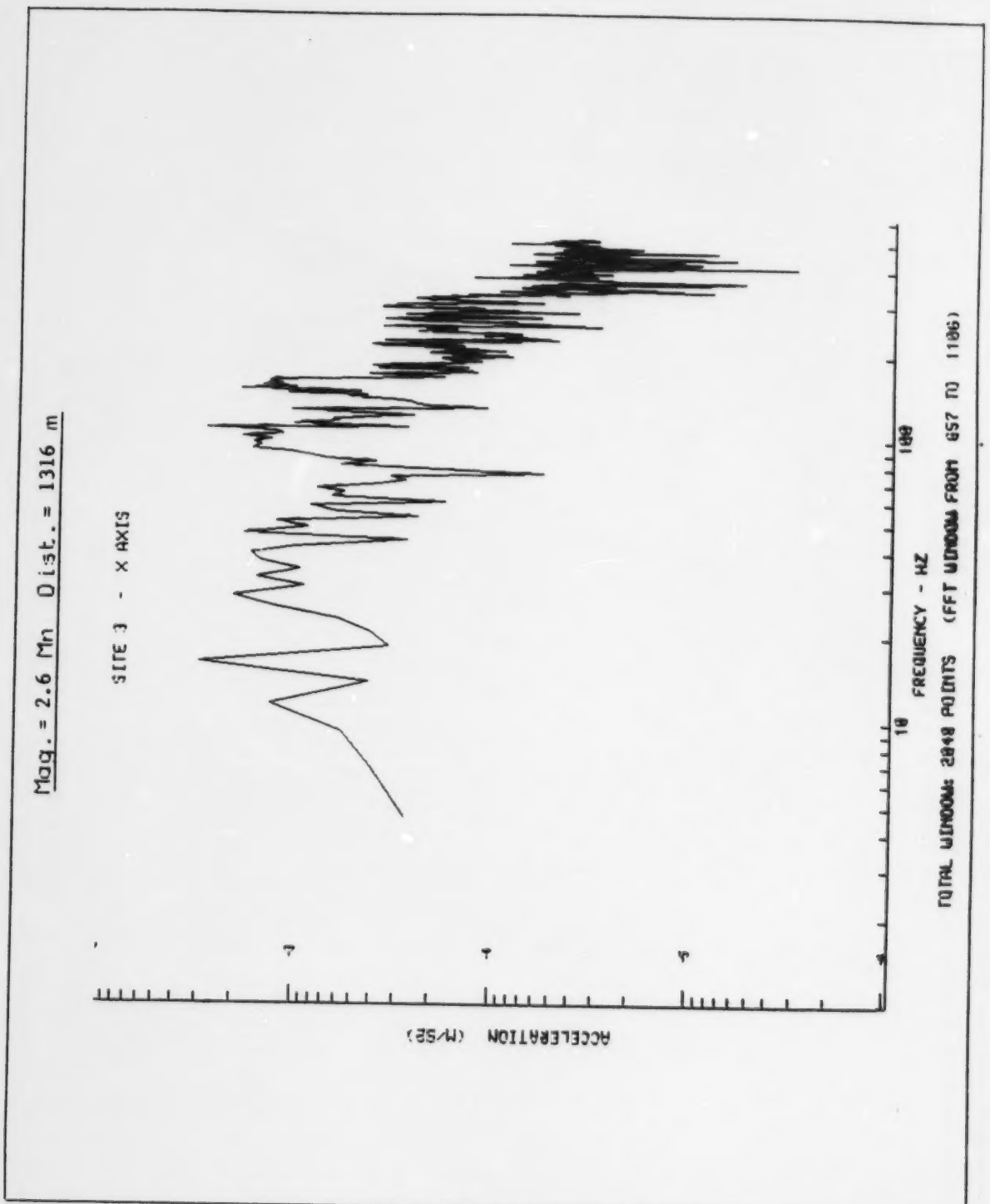

Fig. 3.5.1 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

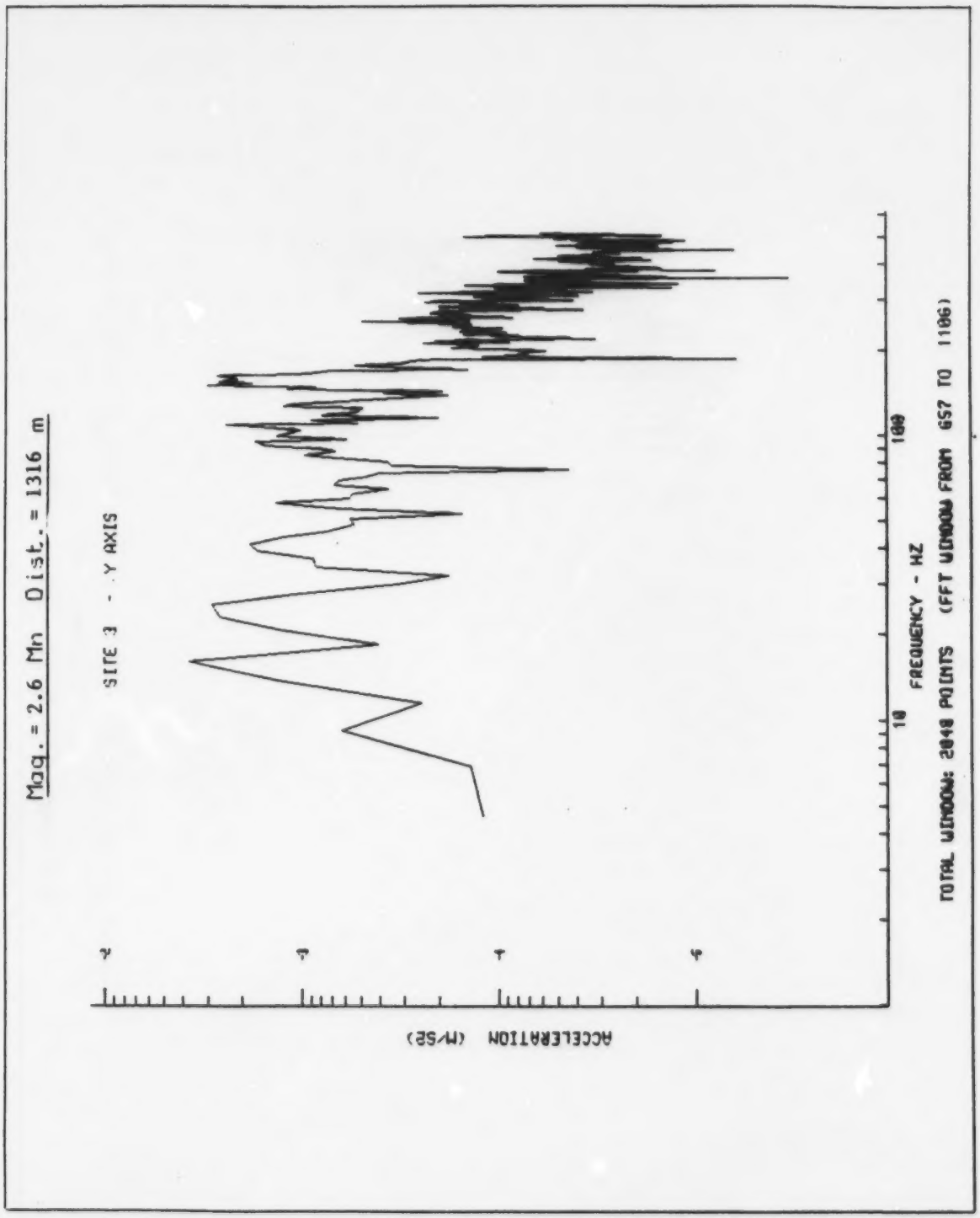

Fig. 3.5.2 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

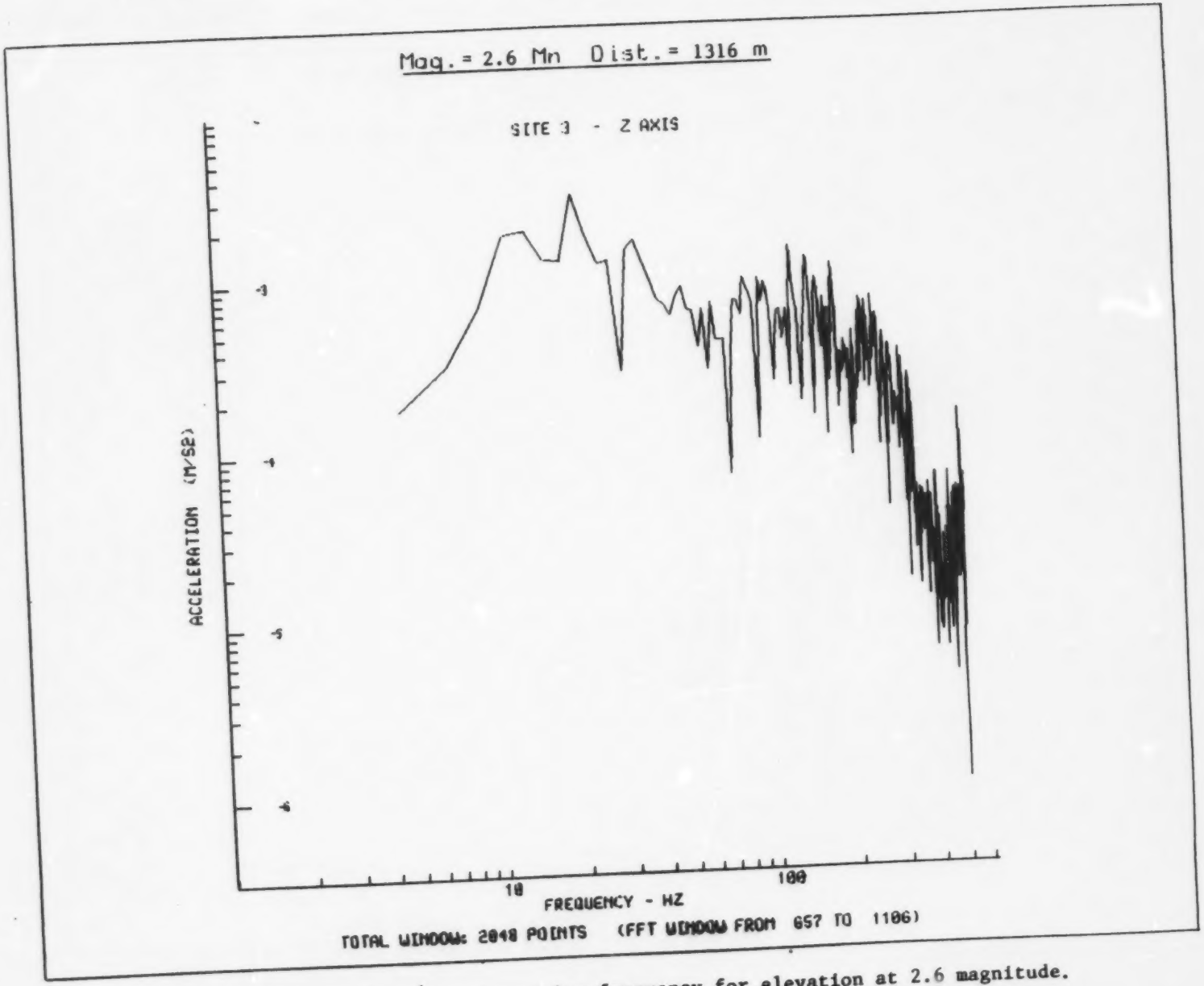

Fig. 3.5.3 - Log acceleration versus log frequency for elevation at 2.6 magnitude.

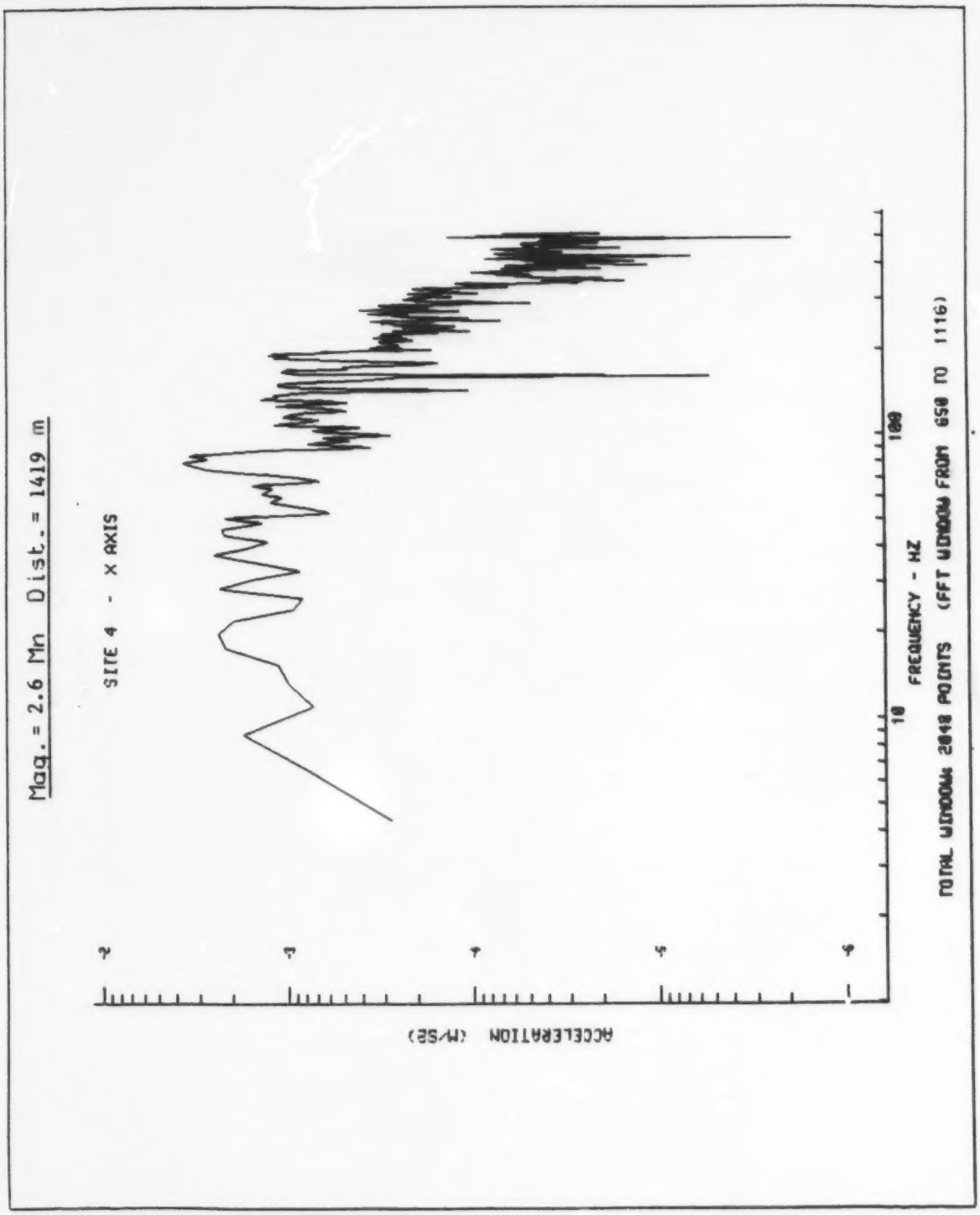

Fig. 3.6.1 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

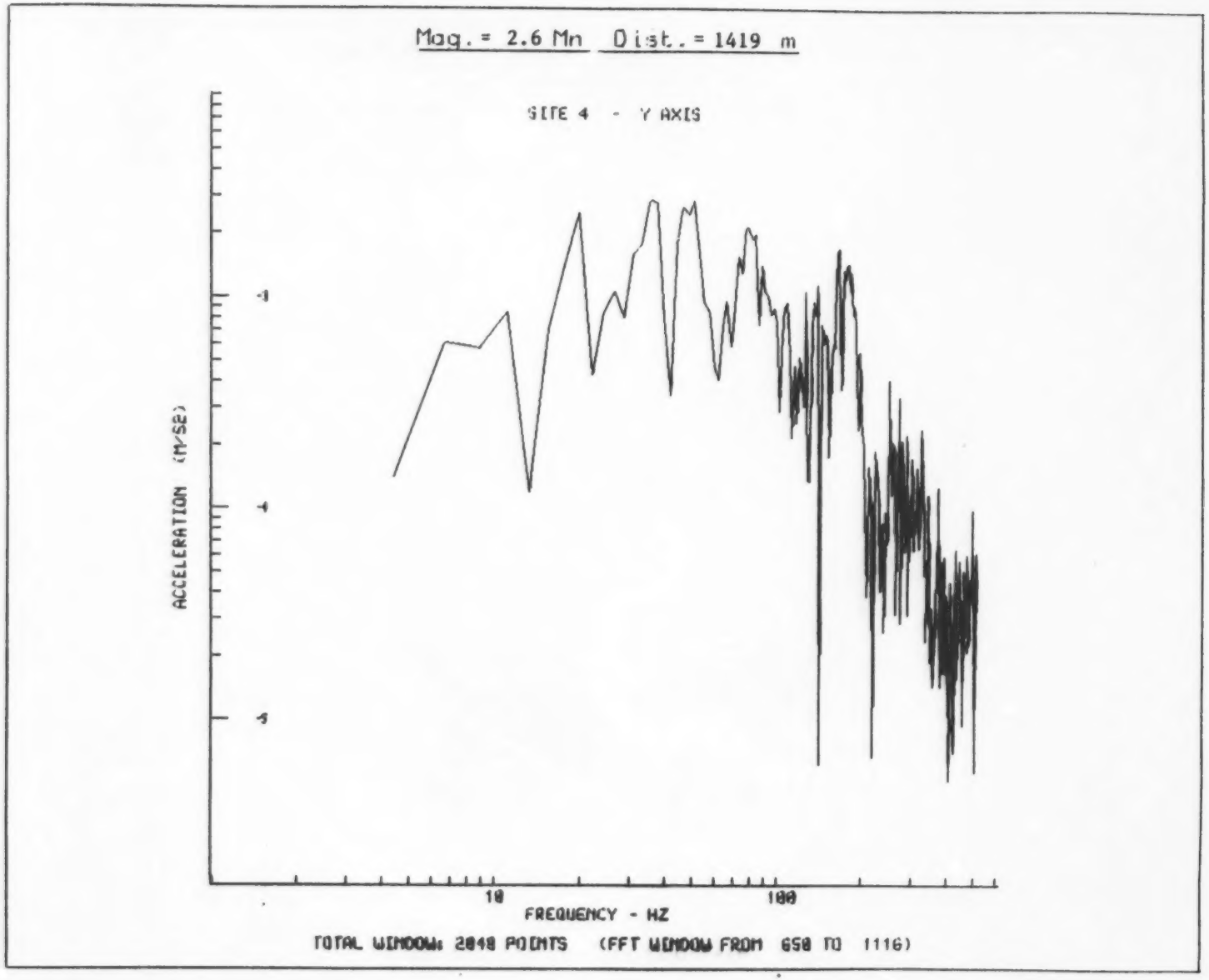
Mag. = 2.6 Mn Dist. = 1419 m
SITE 4 - Y AXIS
ACCELERATION (M/SE)
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2048 POINTS (FFT WINDOW FROM 658 TO 1116)

Fig. 3.6.2 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

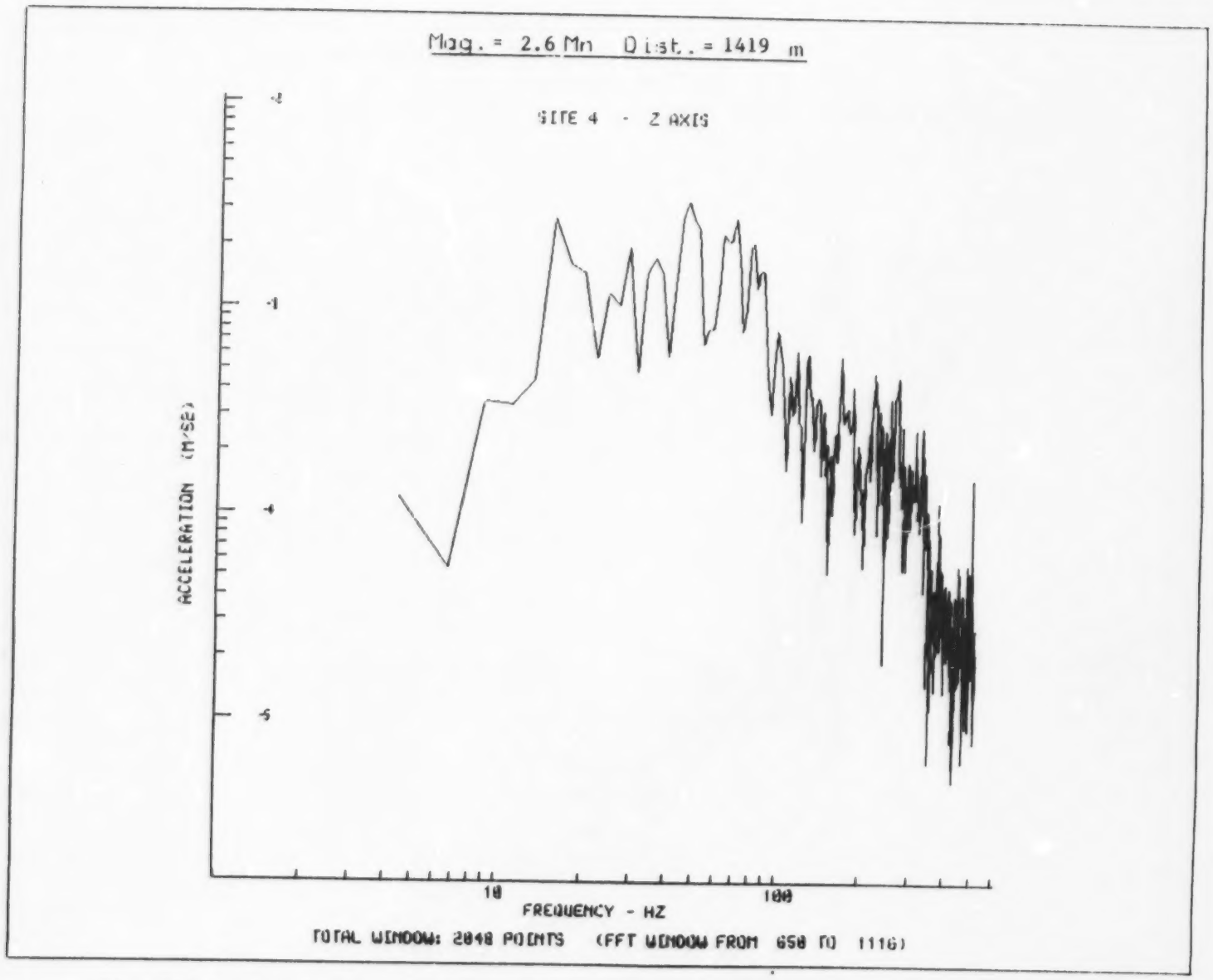

Fig. 3.6.3 - Log acceleration versus log frequency for elevation at 2.6 magnitude.

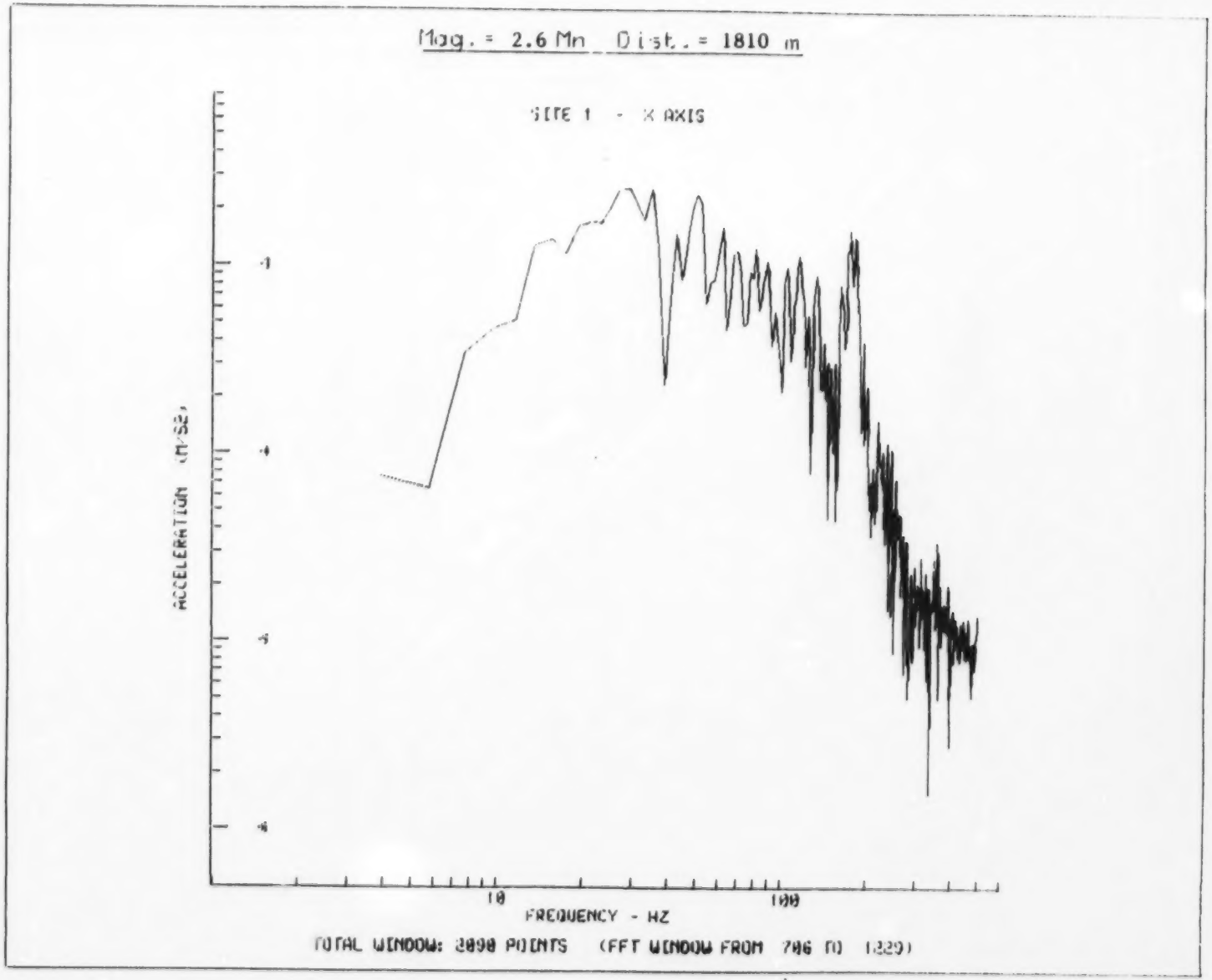
Mag. = 2.6 Mn Dist. = 1810 m
SITE 1 - X AXIS
ACCELERATION (M/S2)
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2098 POINTS (FFT WINDOW FROM 786 TO 1329)

Fig. 3.7.1 - Log acceleration versus log frequency for east/west axis at 2.6 magnitude.

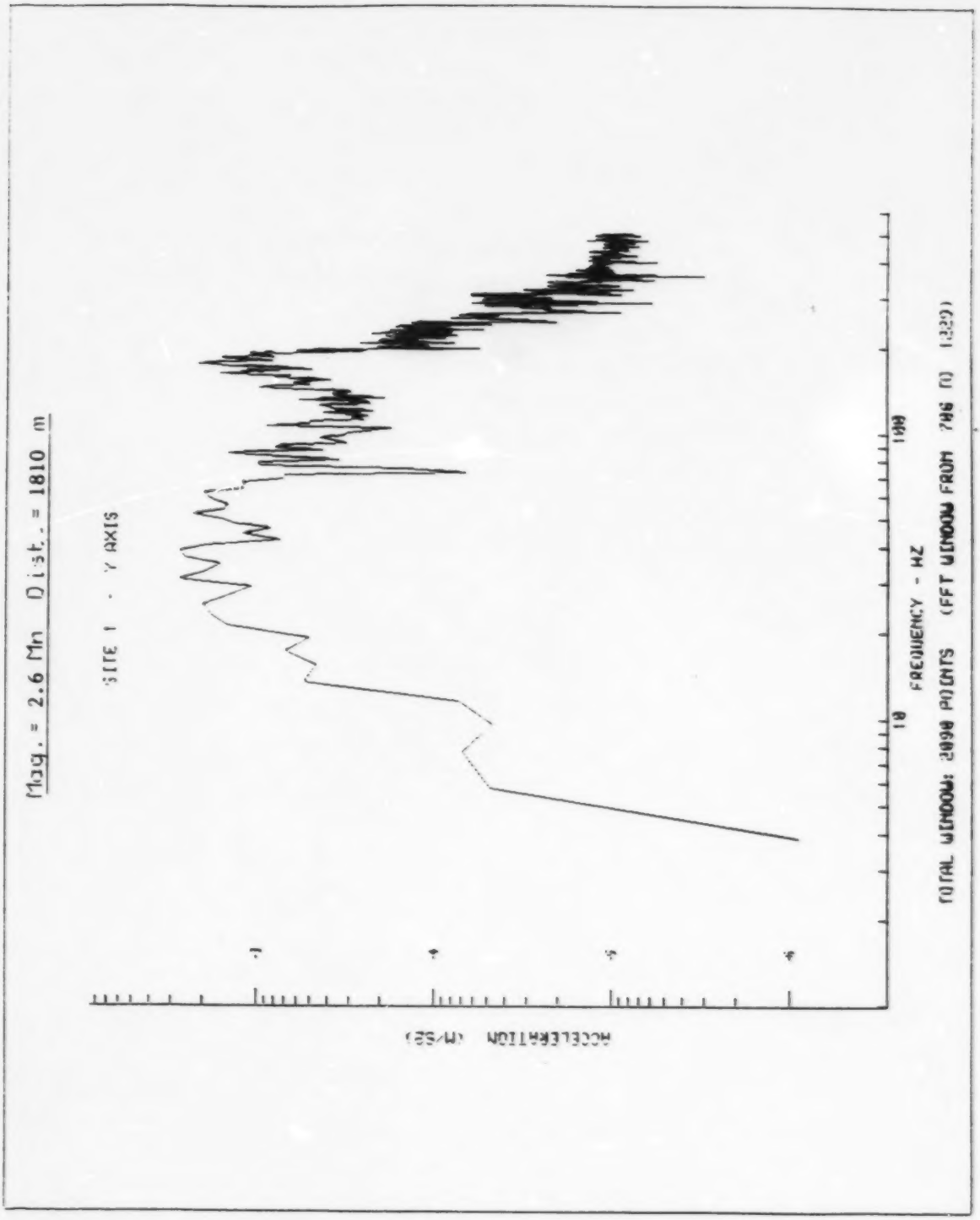

Fig. 3.7.2 - Log acceleration versus log frequency for north/south axis at 2.6 magnitude.

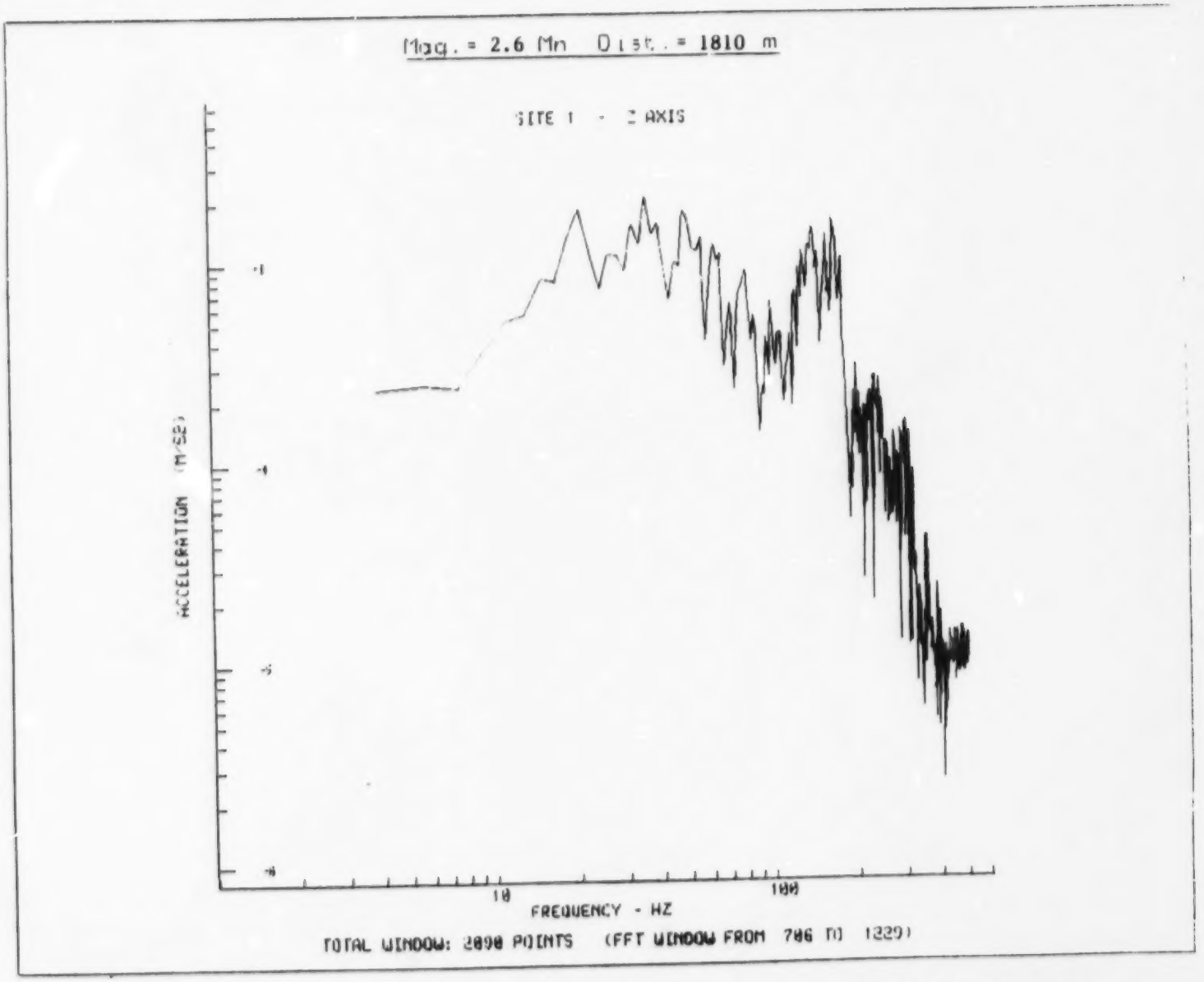
Mag. = 2.6 Mn Dist. = 1810 m
SITE 1 - Z AXIS
ACCELERATION (M/S2)
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2898 POINTS (FFT WINDOW FROM 706 TO 1229)

Fig. 3.7.3 - Log acceleration versus log frequency for elevation at 2.6 magnitude.

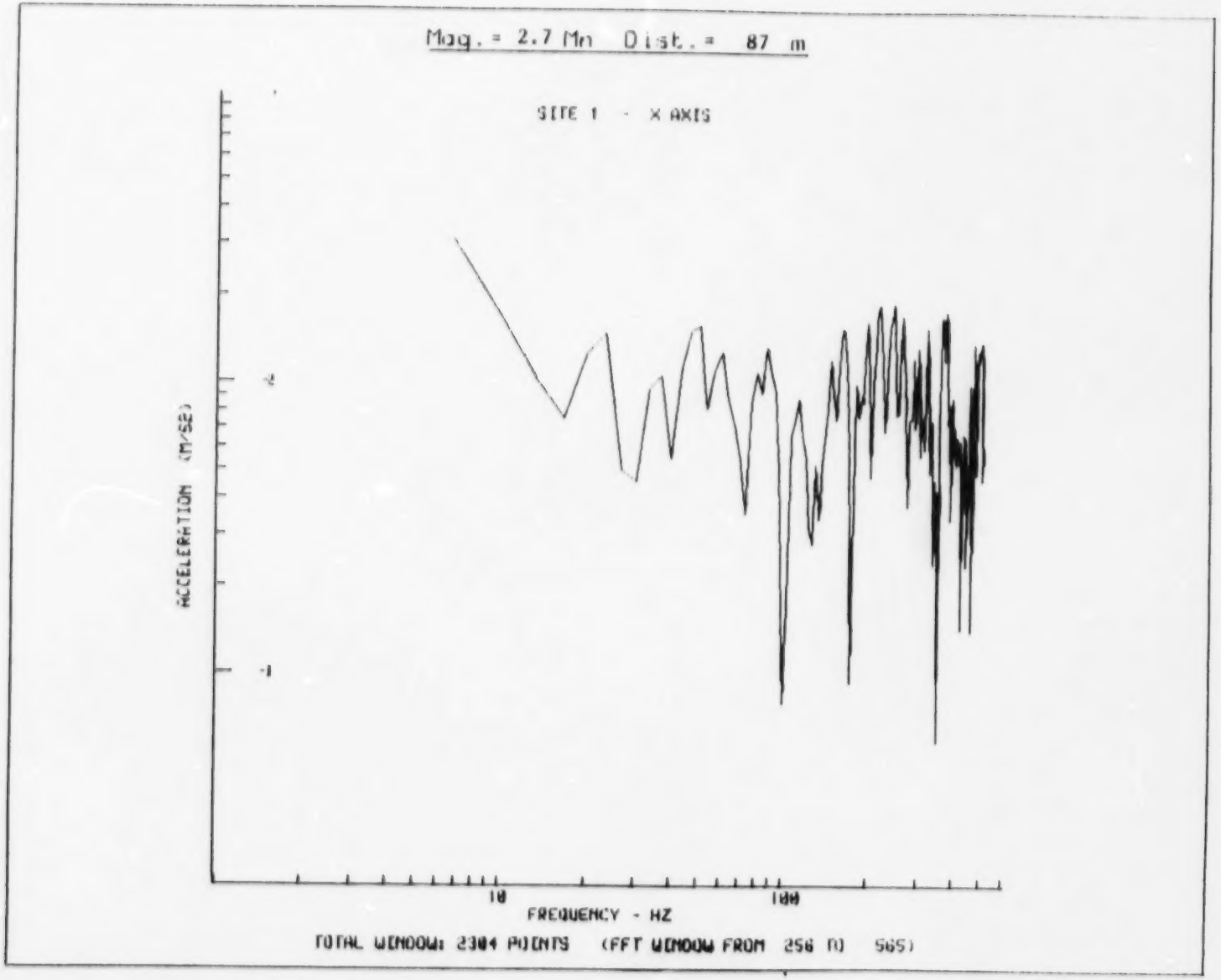

Fig. 4.1.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

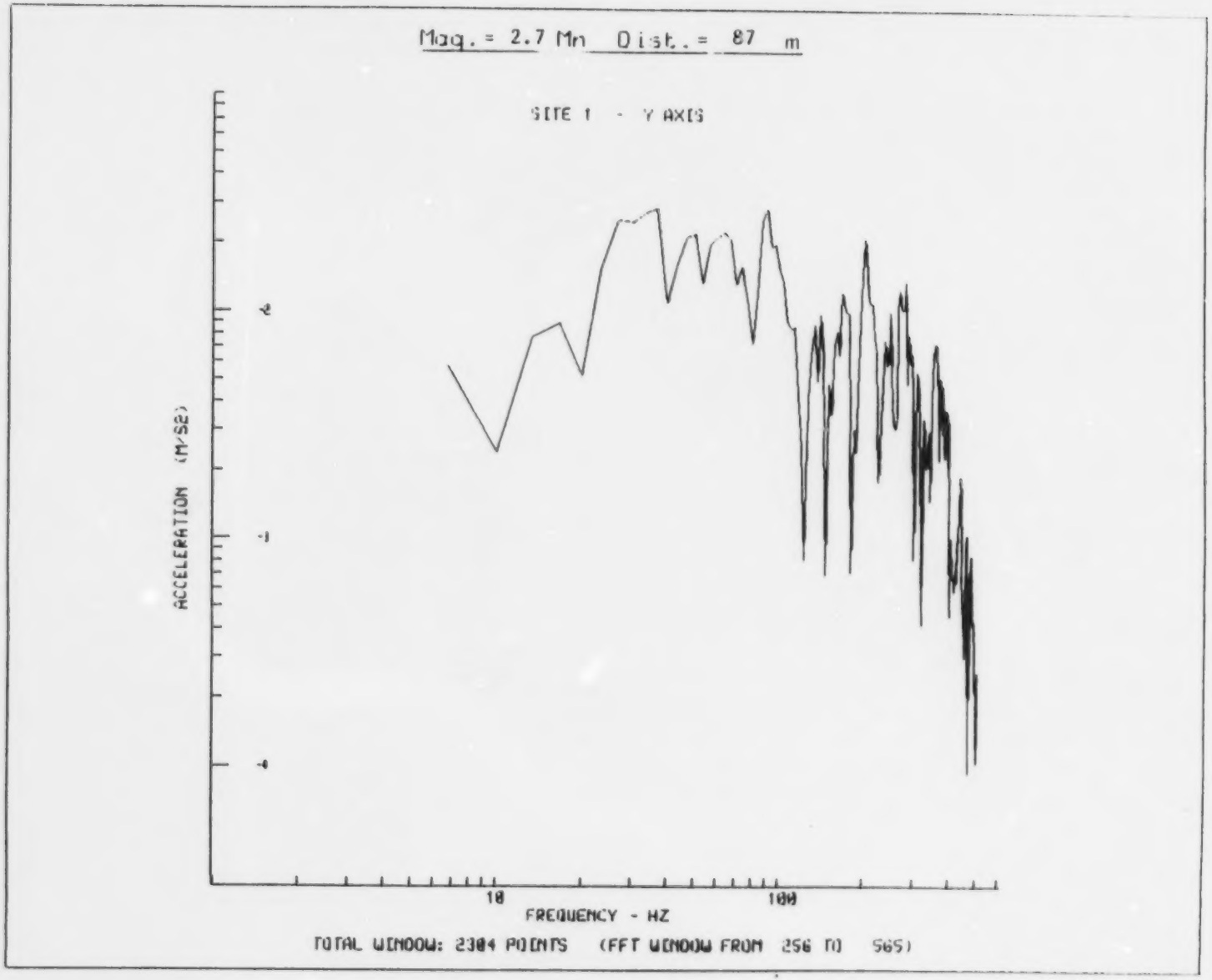

Fig. 4.1.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

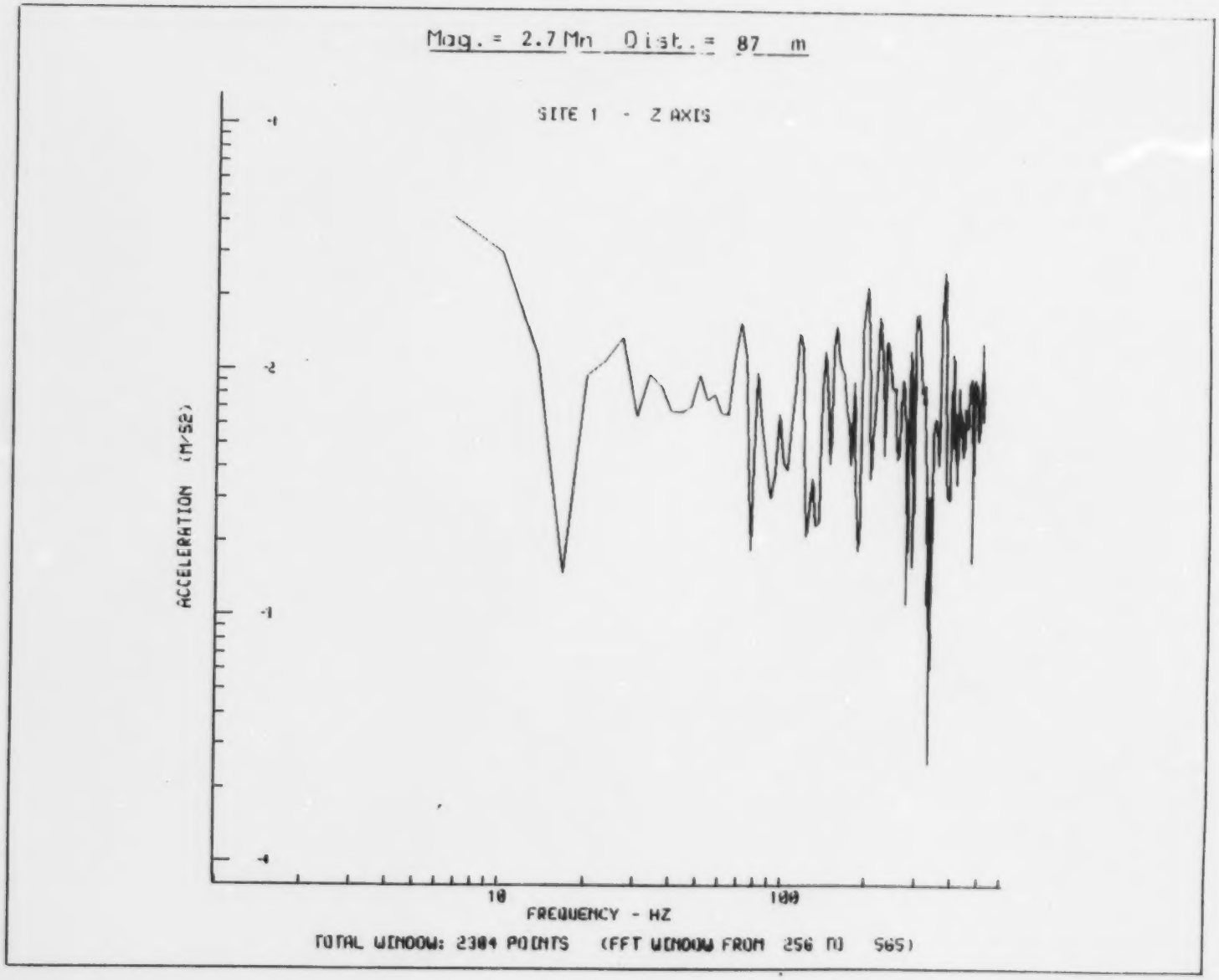

Fig. 4.1.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

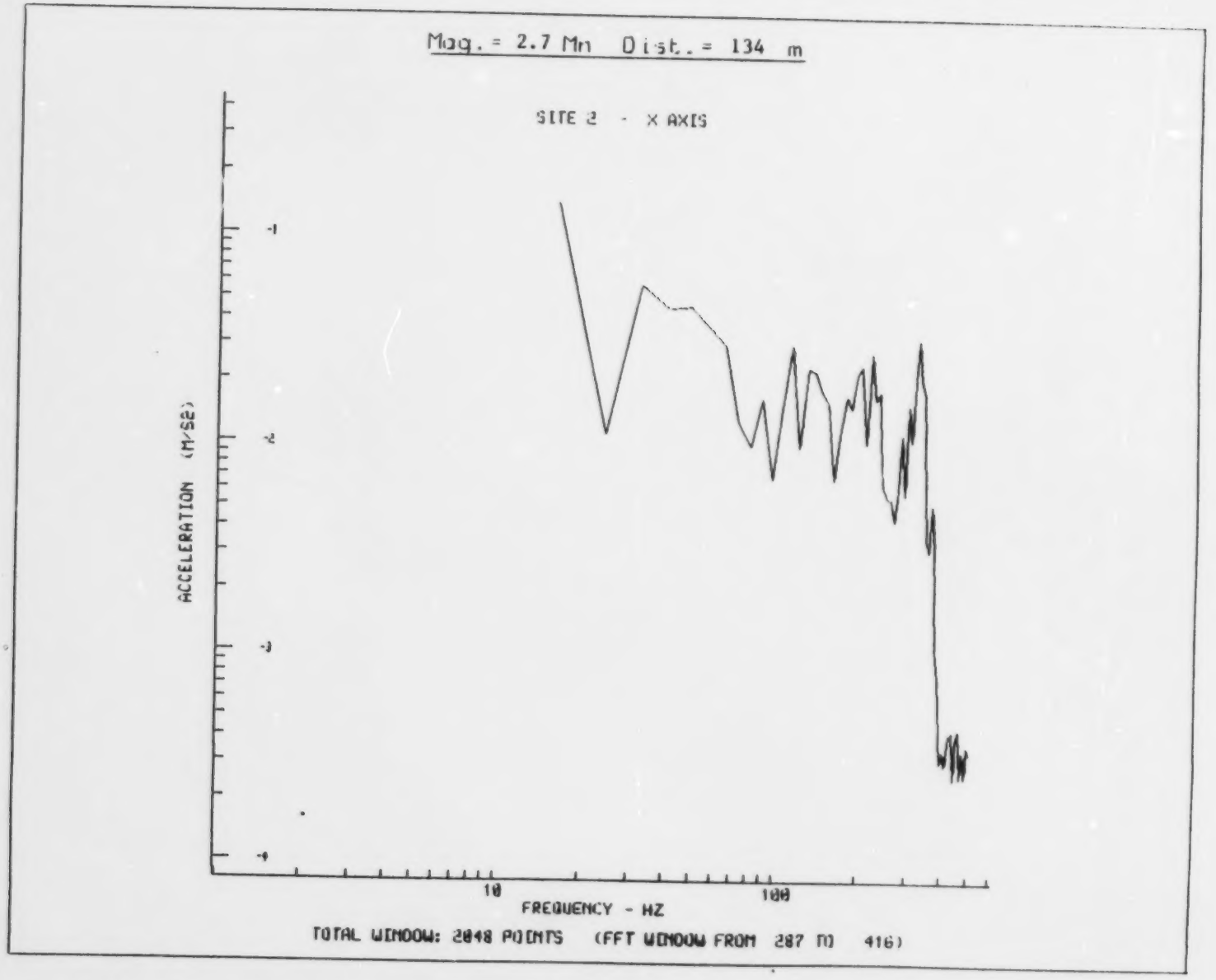

Fig. 4.2.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

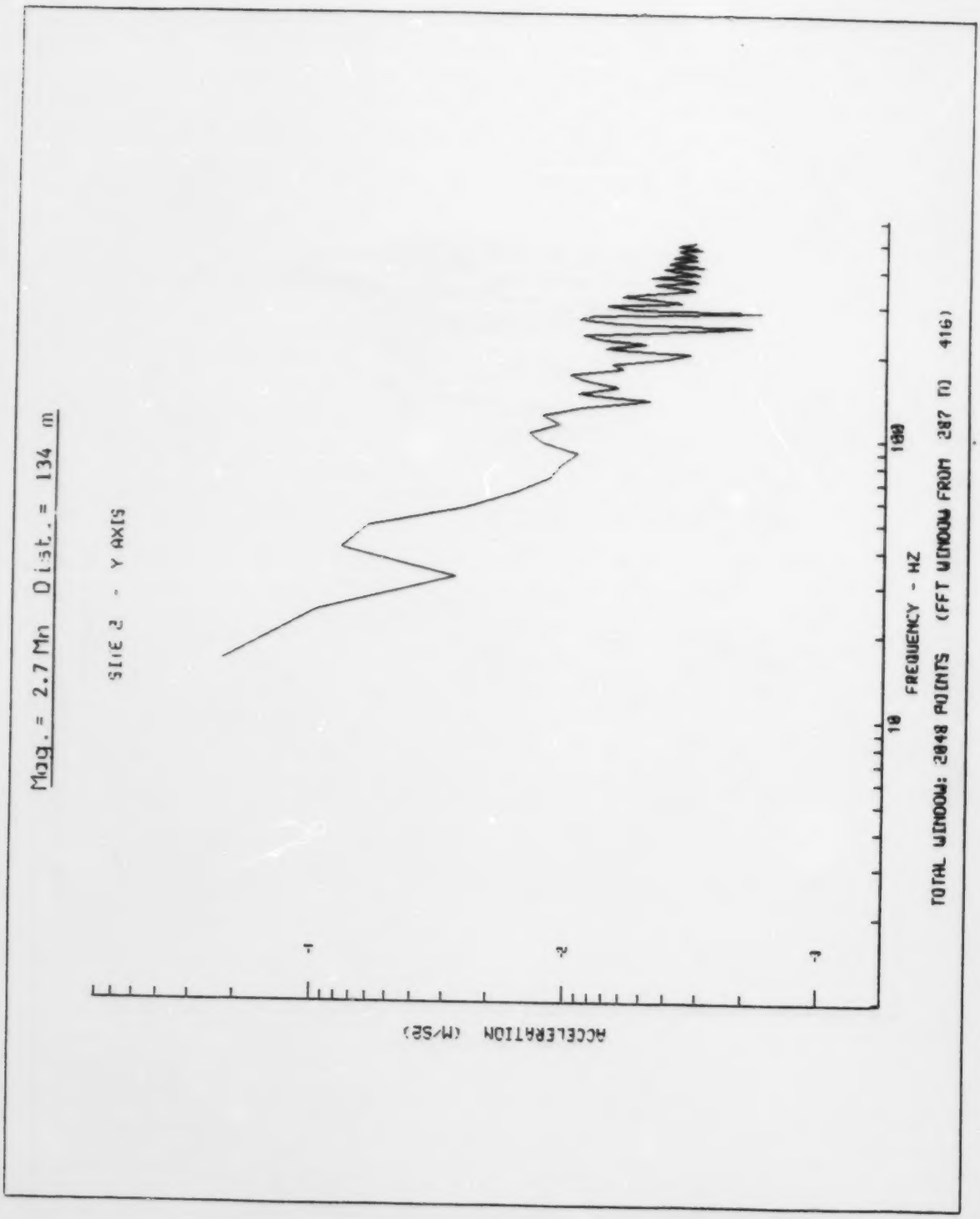

Fig. 4.2.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

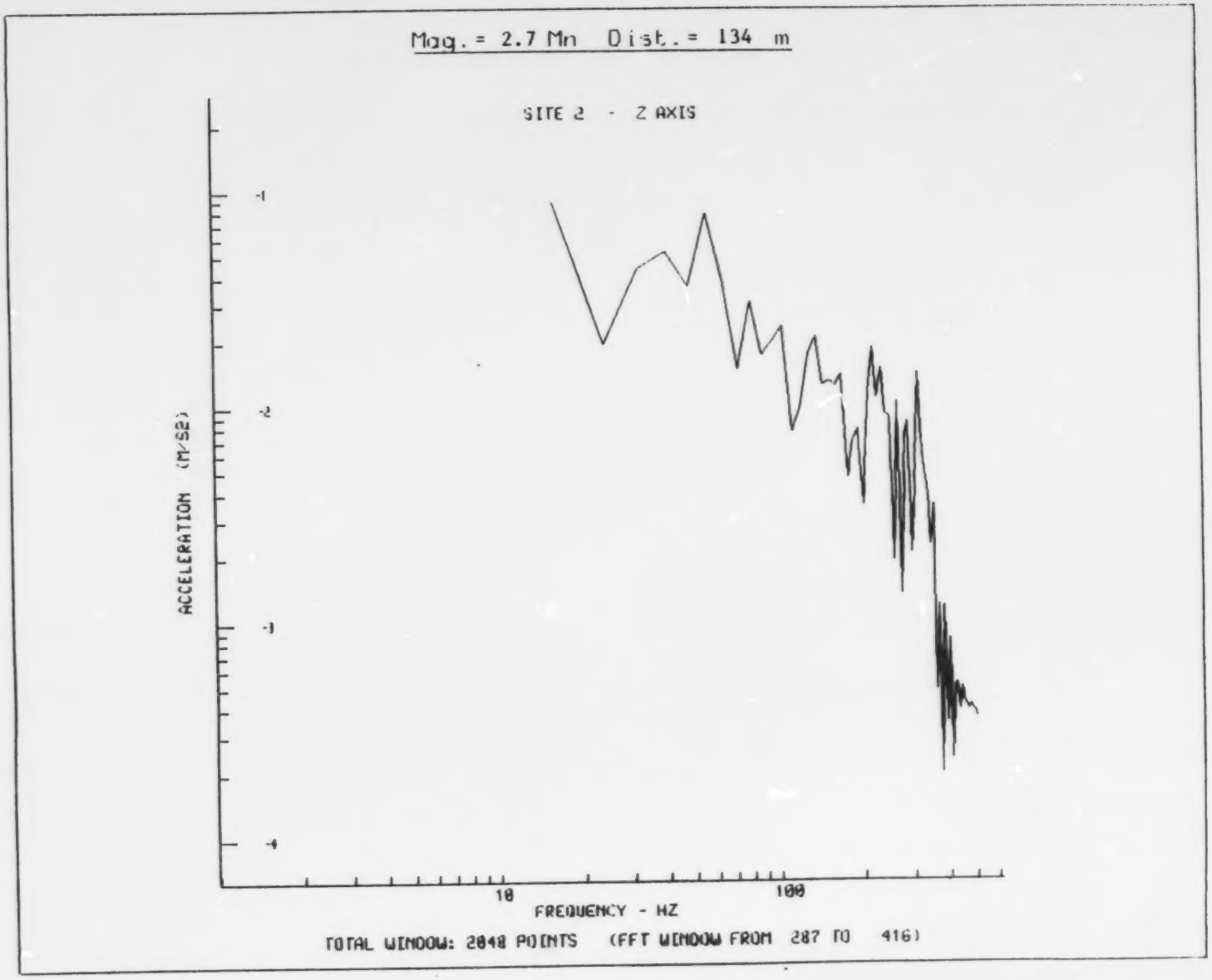

Fig. 4.2.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

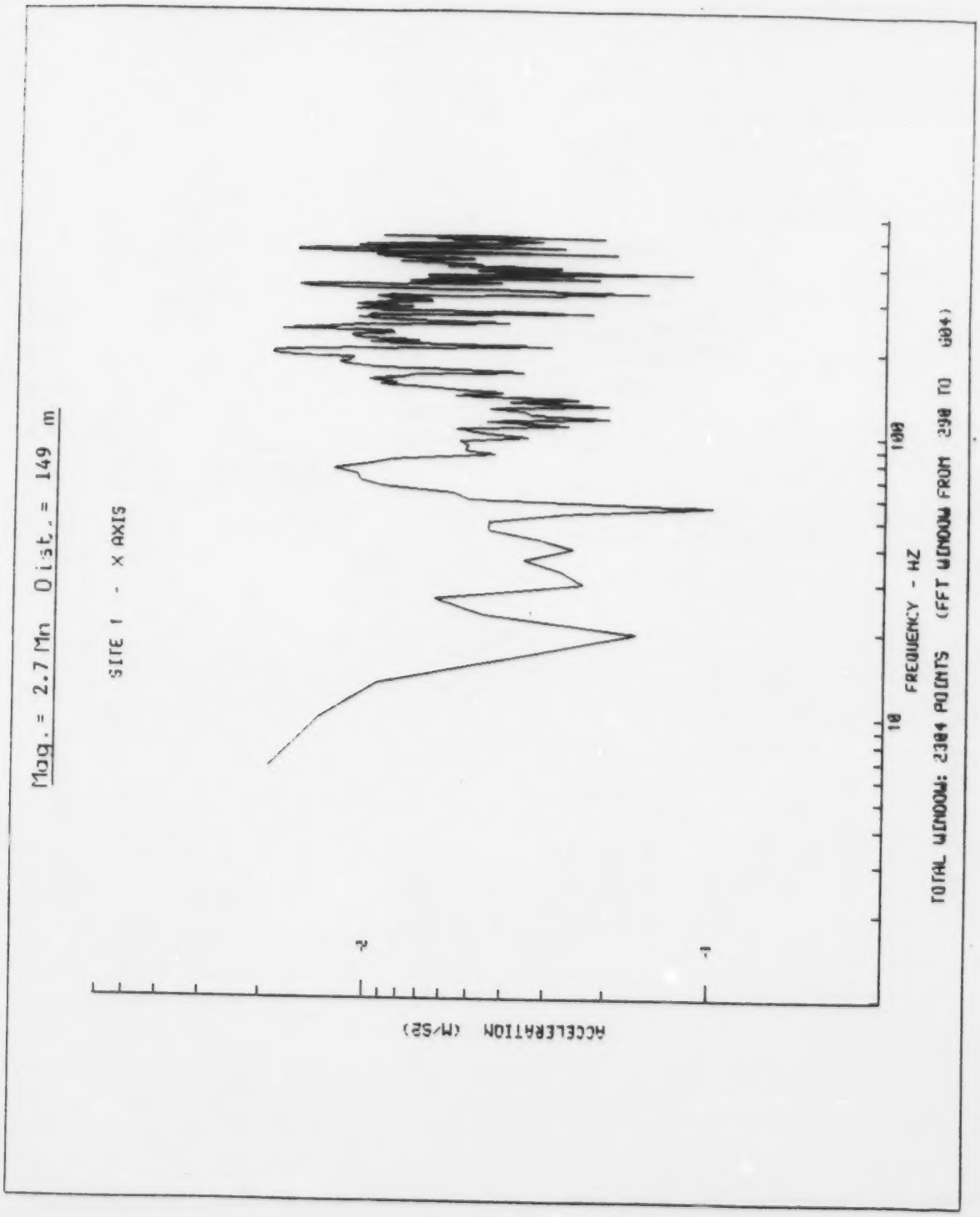

Fig. 4.3.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

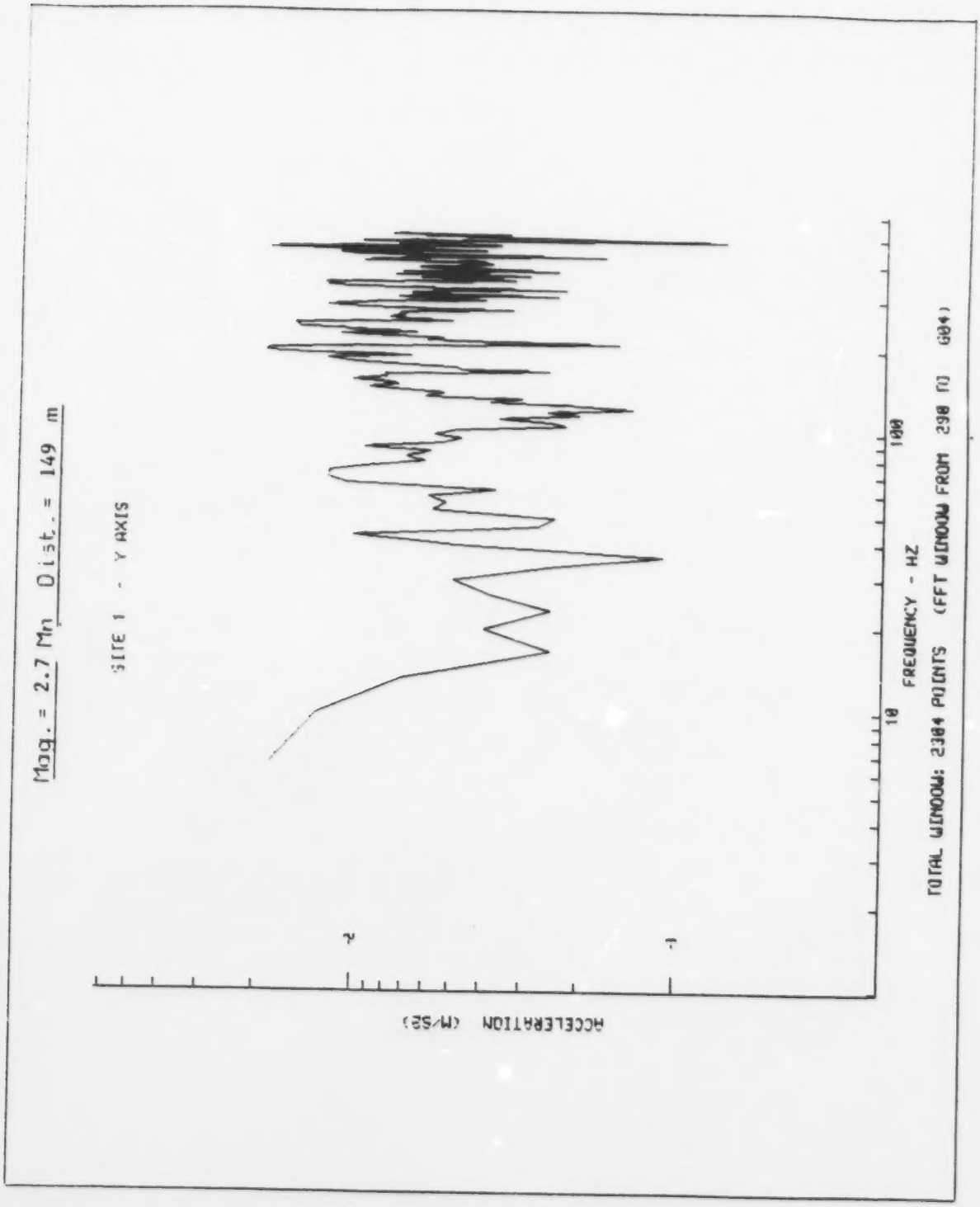

Fig. 4.3.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

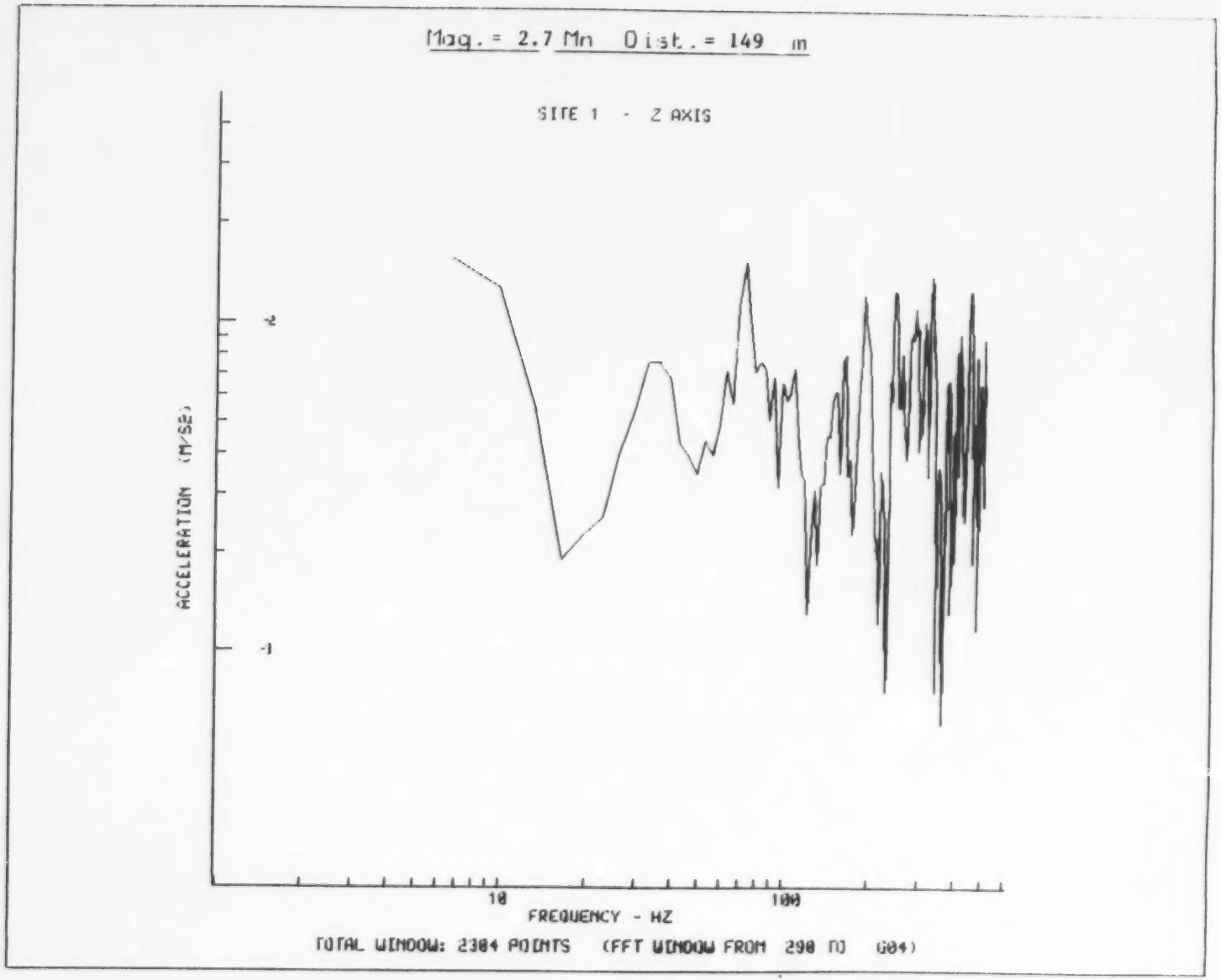

Fig. 4.3.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

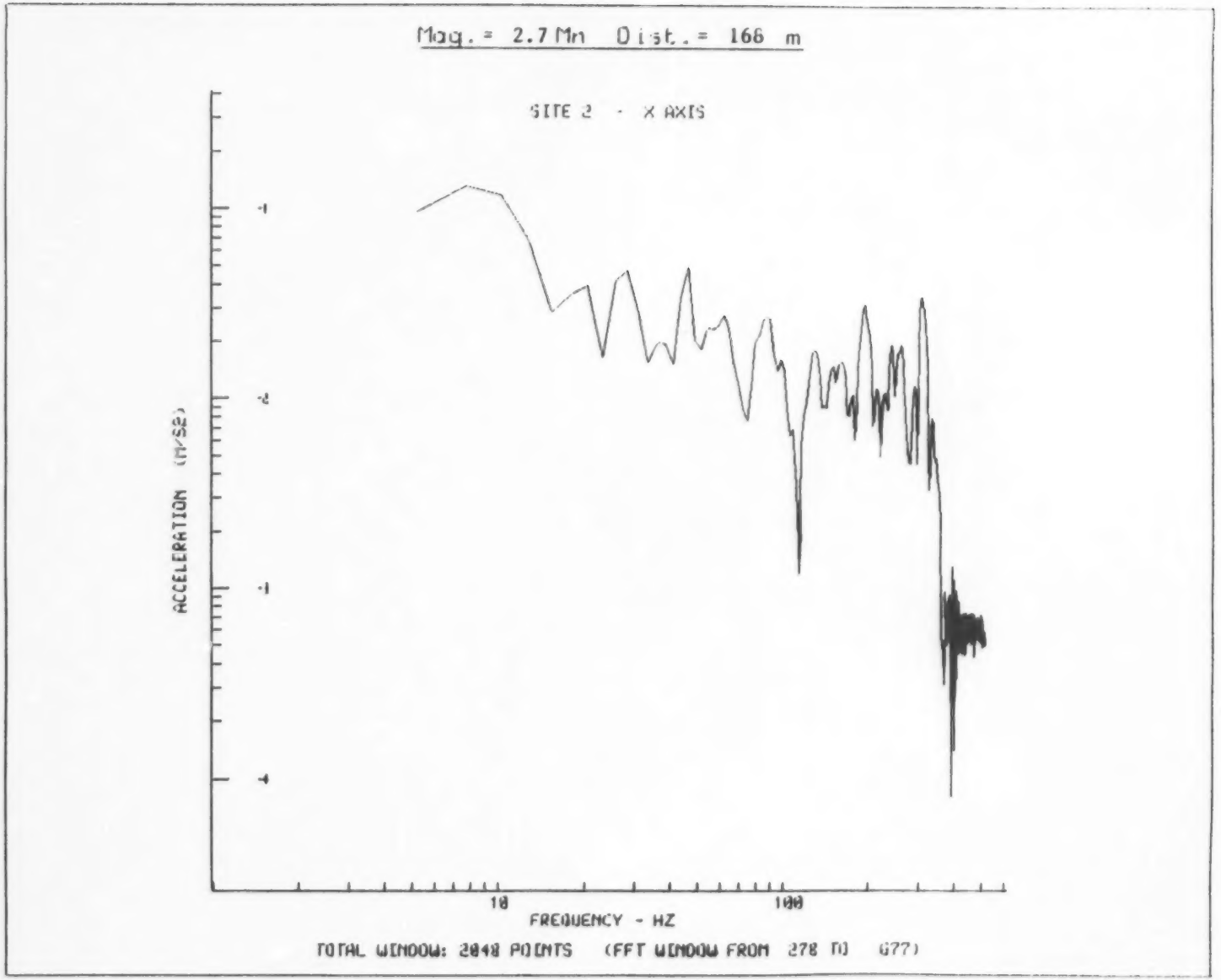

Fig. 4.4.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

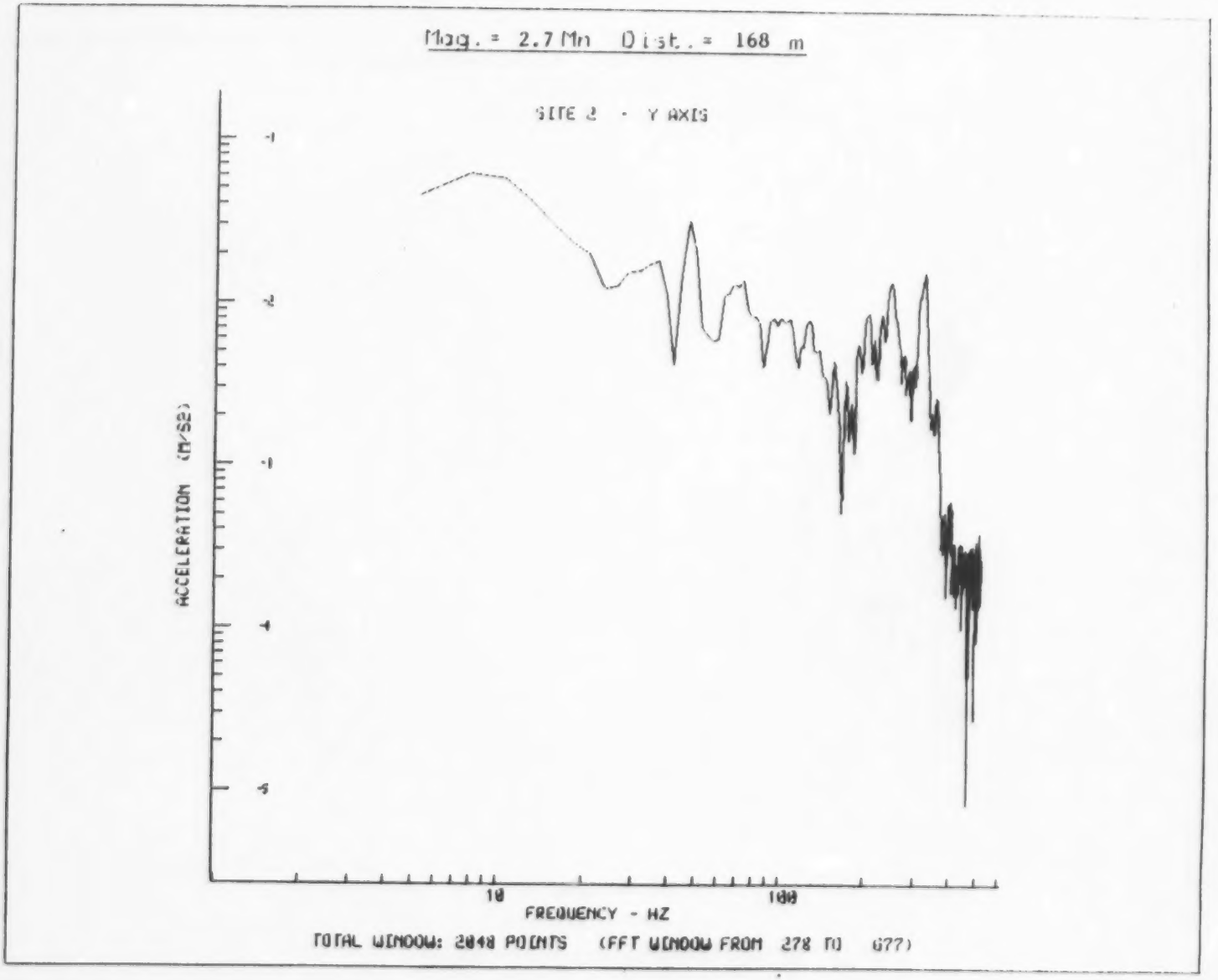

Fig. 4.4.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

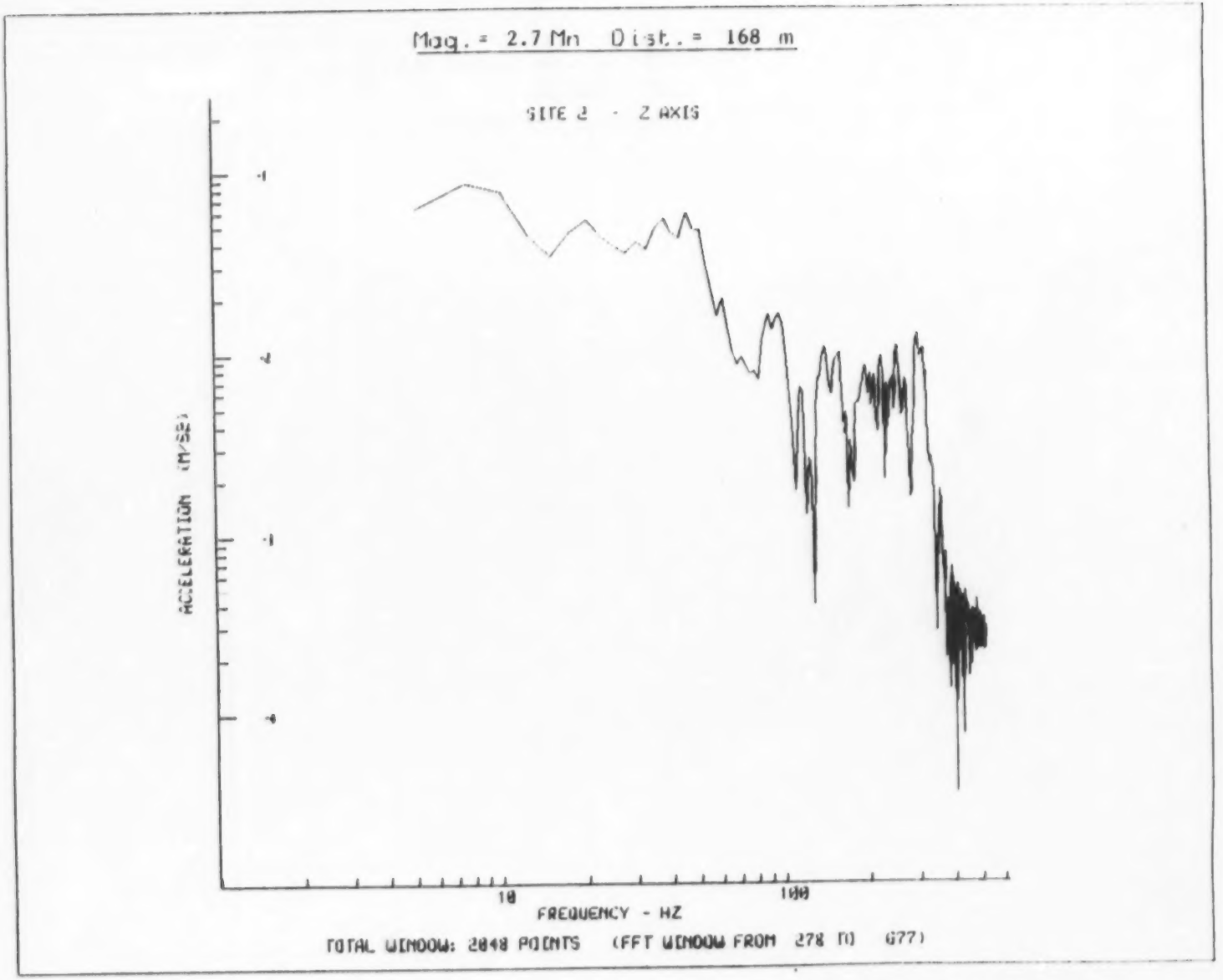

Fig. 4.4.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

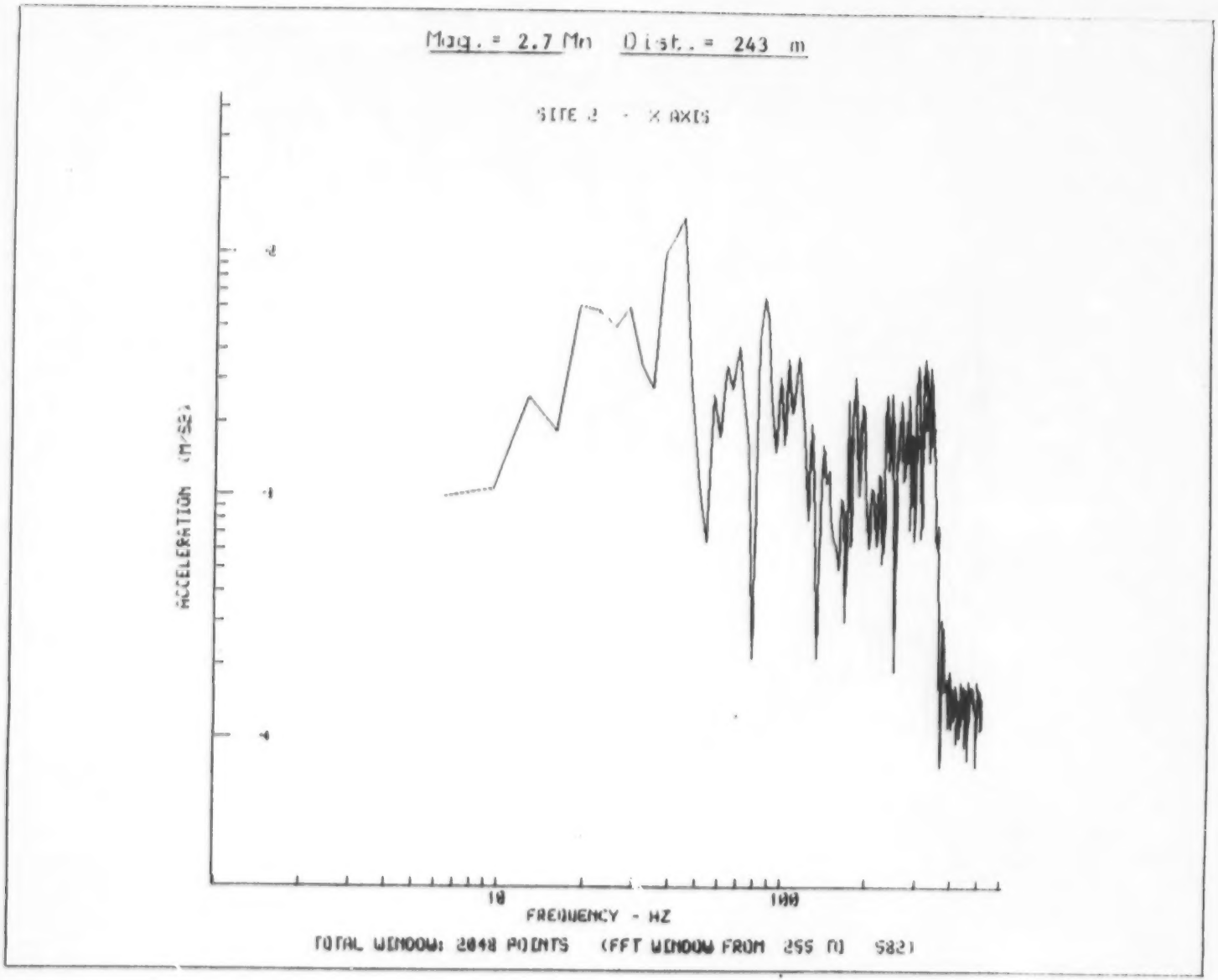

Fig. 4.5.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

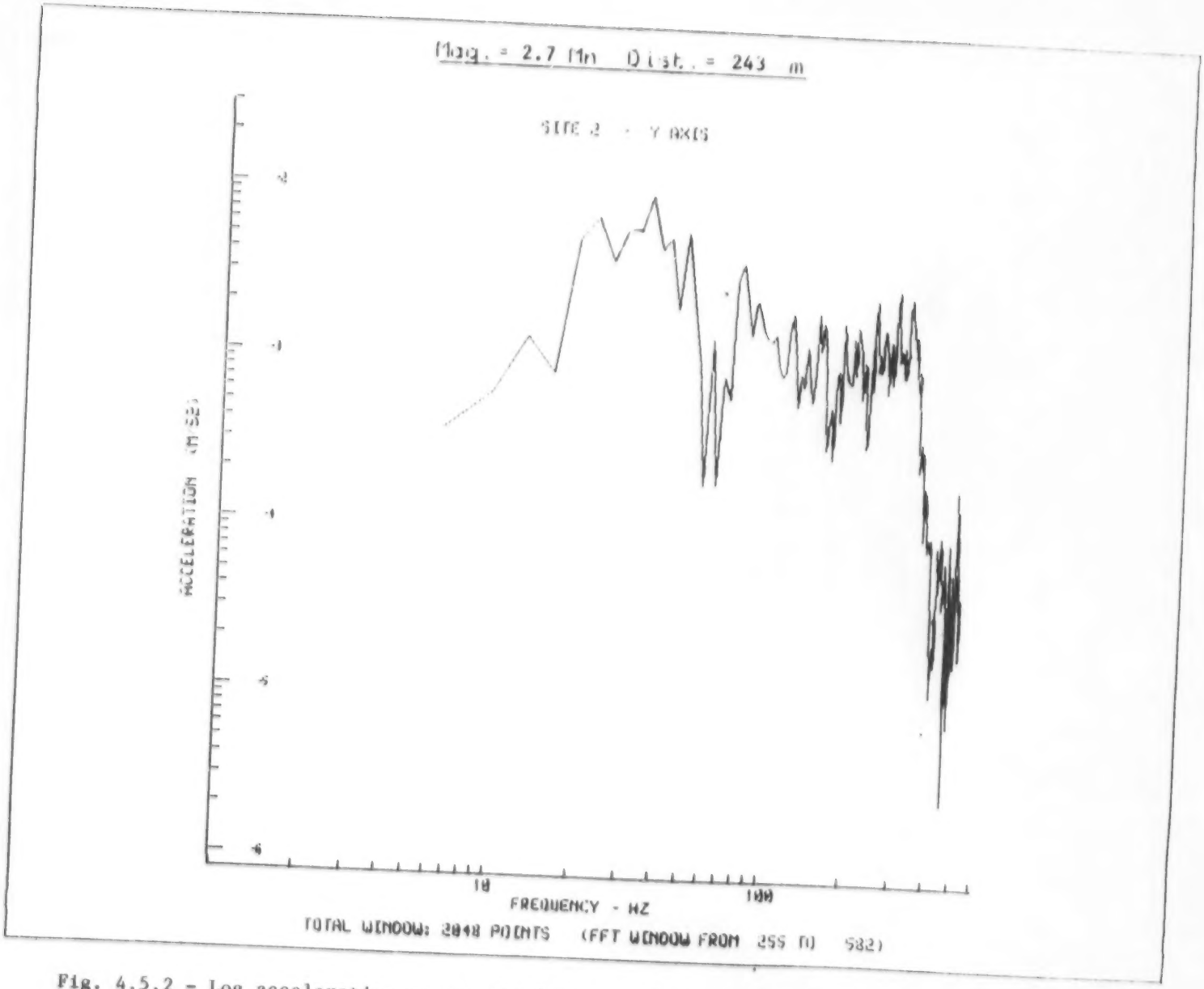

Fig. 4.5.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

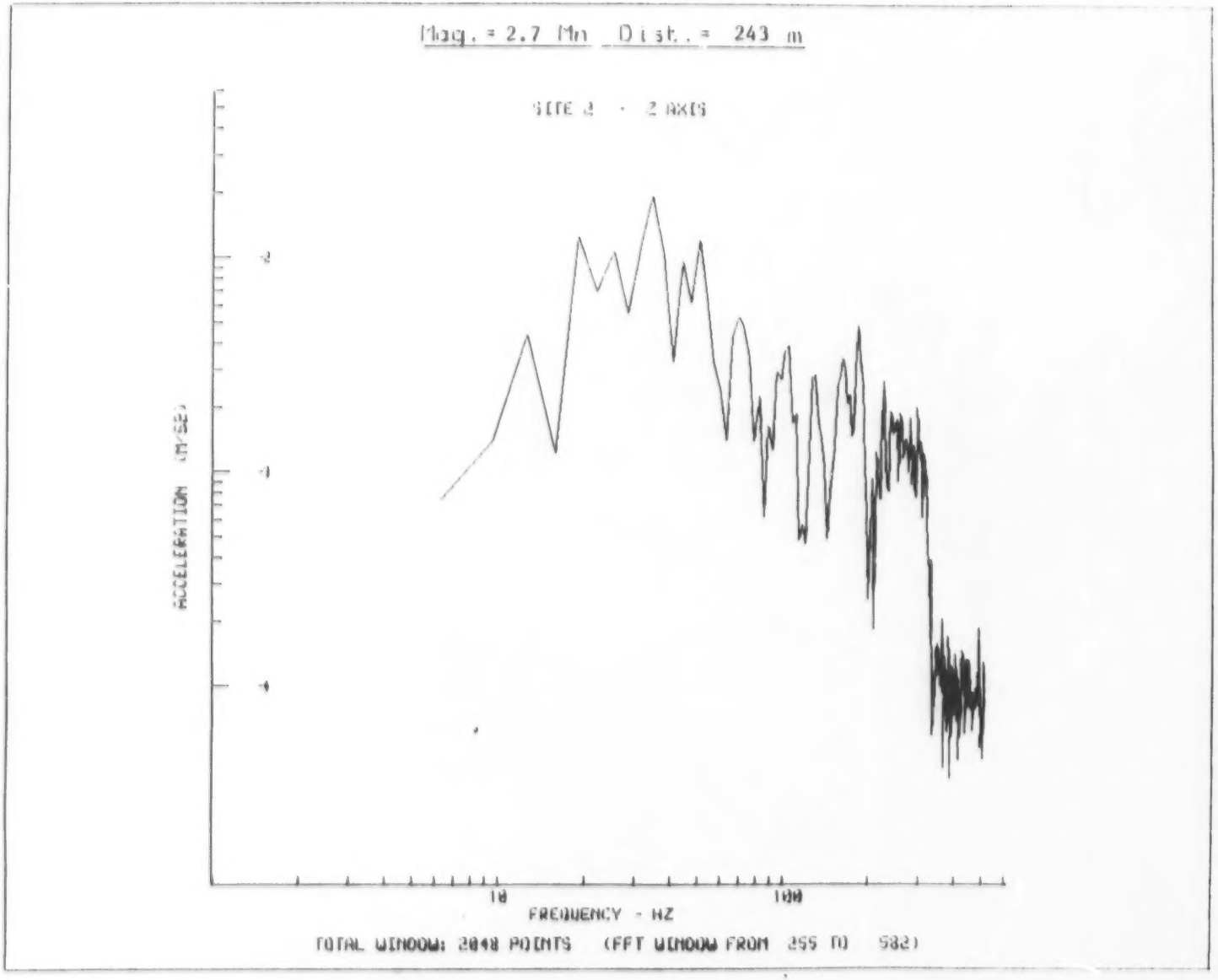

Fig. 4.5.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

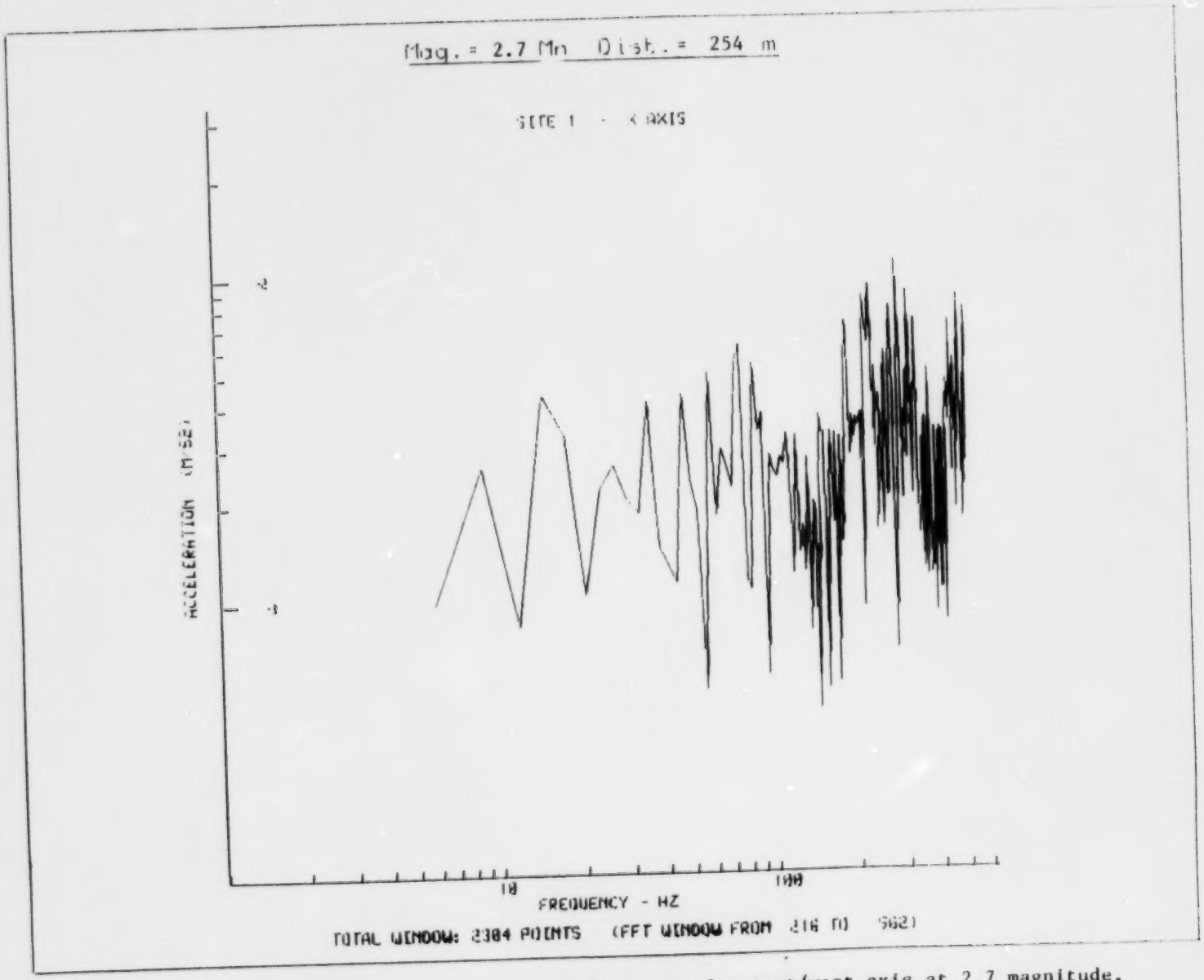

Fig. 4.6.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

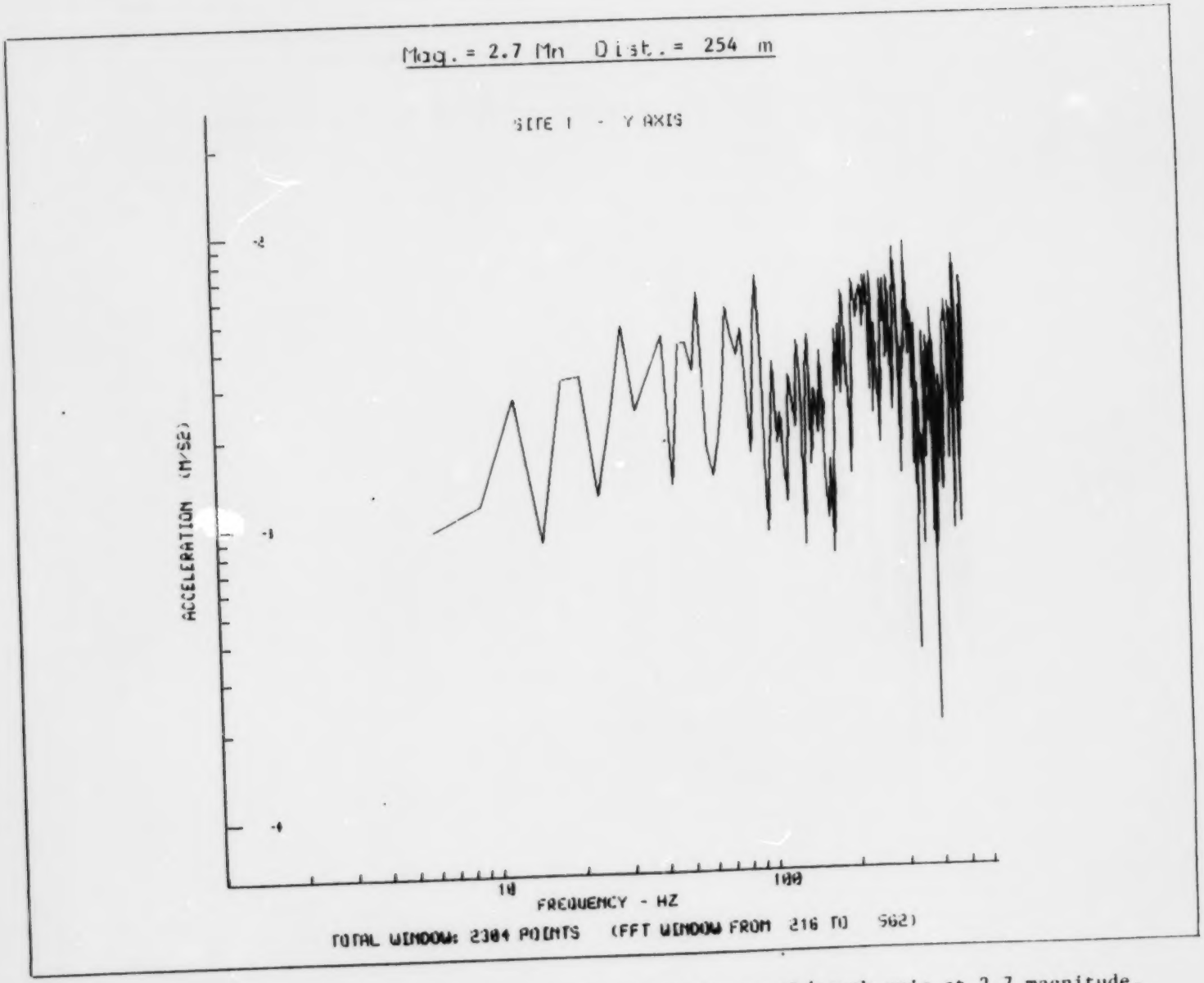

Fig. 4.6.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

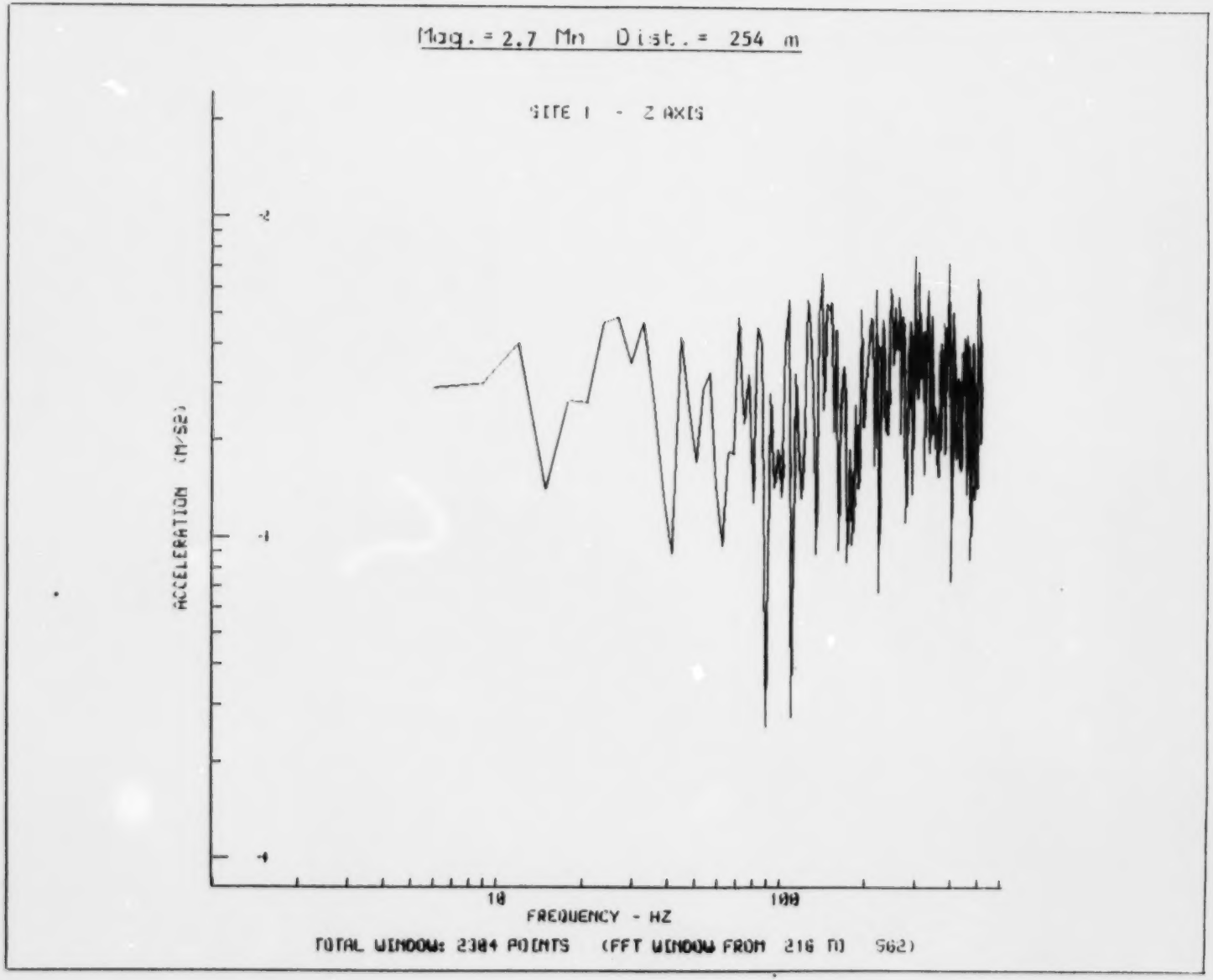

Fig. 4.6.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

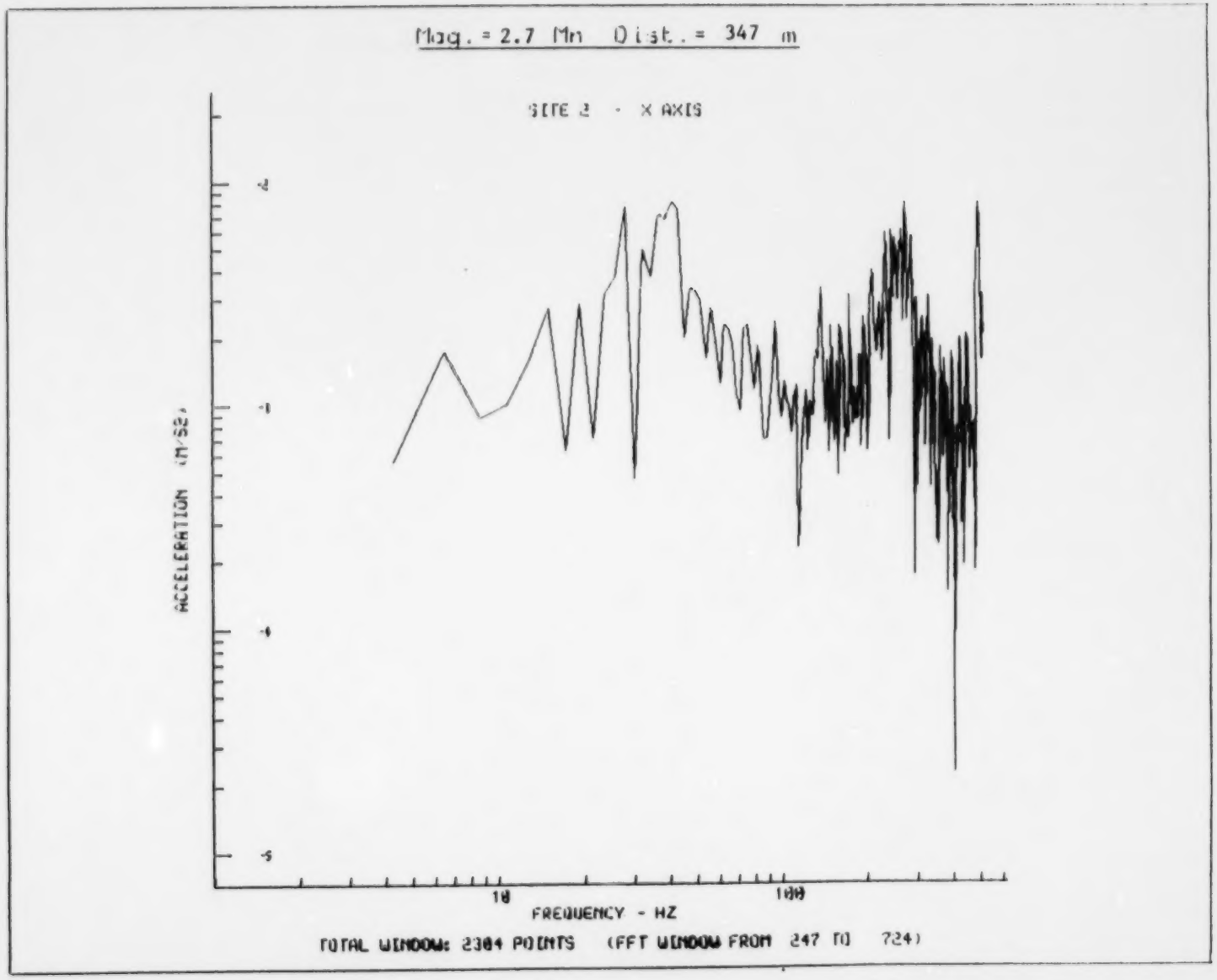

Fig. 4.7.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

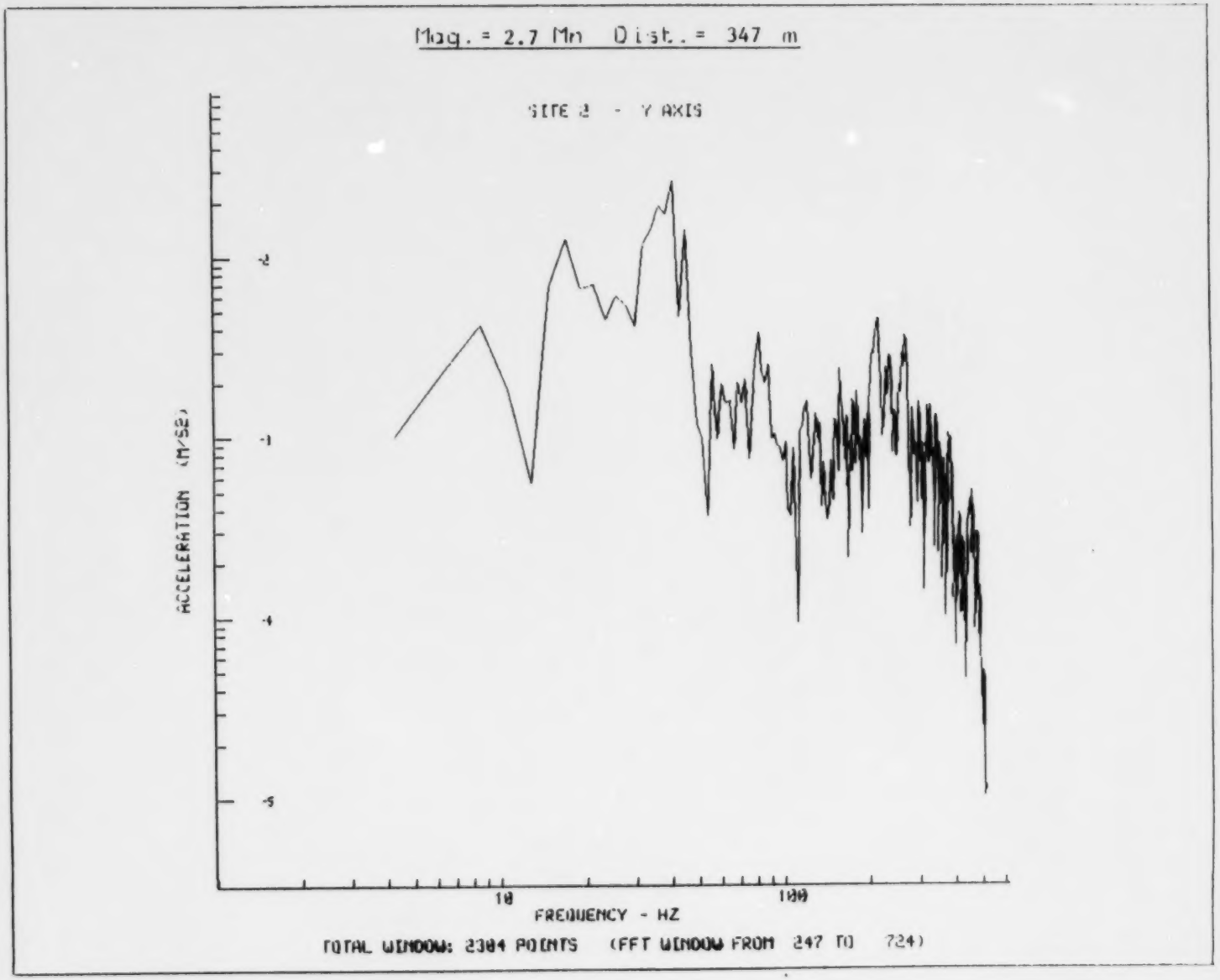

Fig. 4.7.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

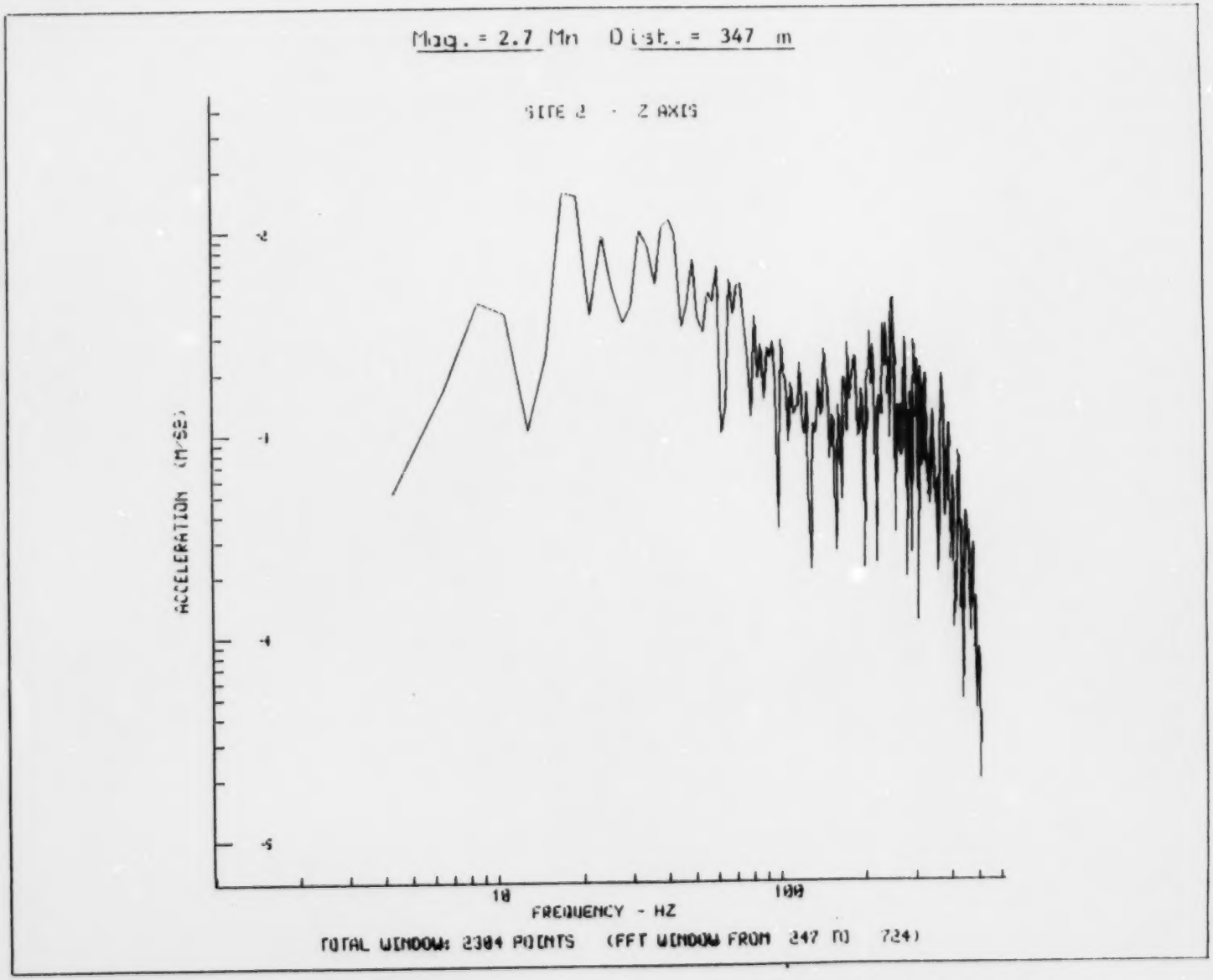

Fig. 4.7.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

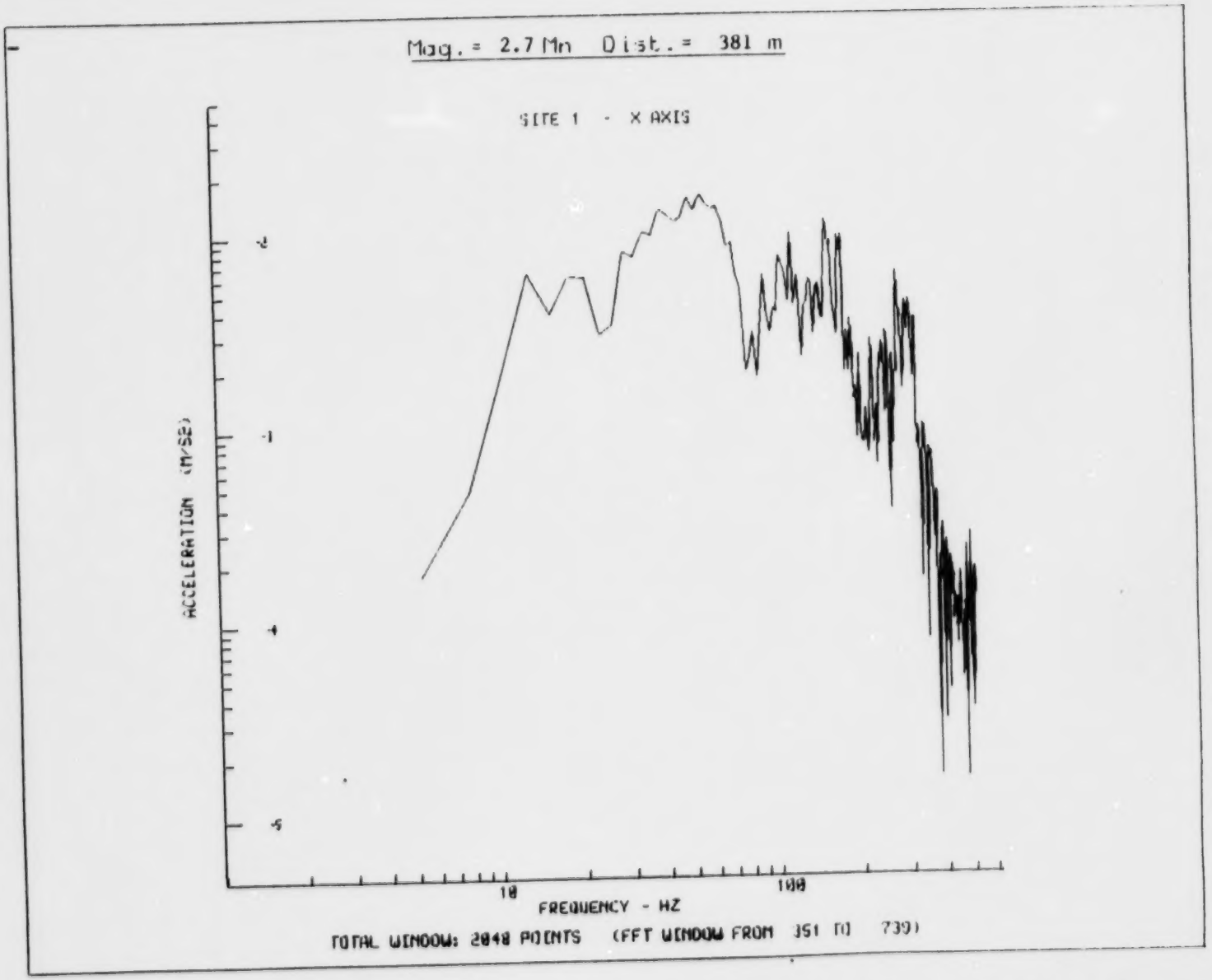

Fig. 4.8.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

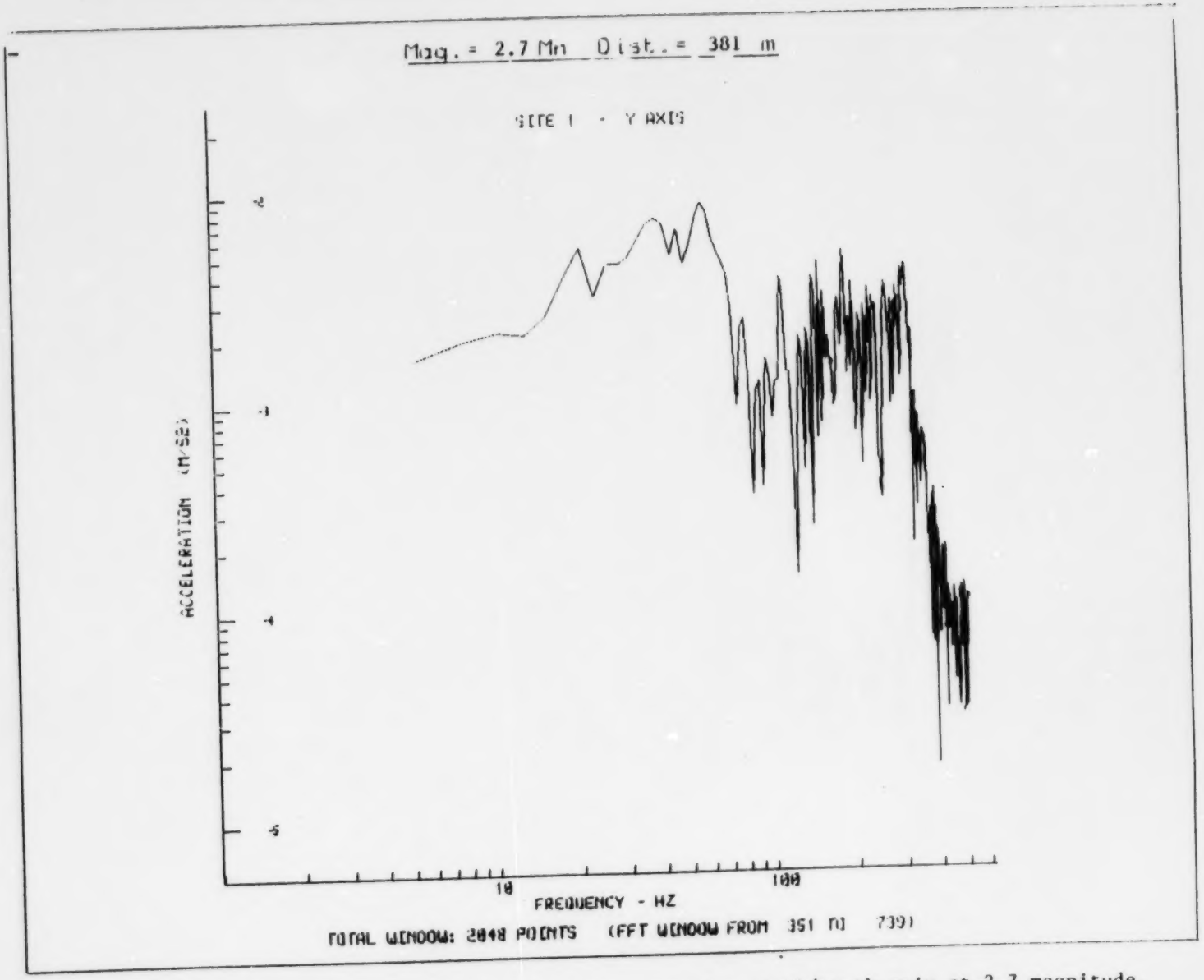

Fig. 4.8.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

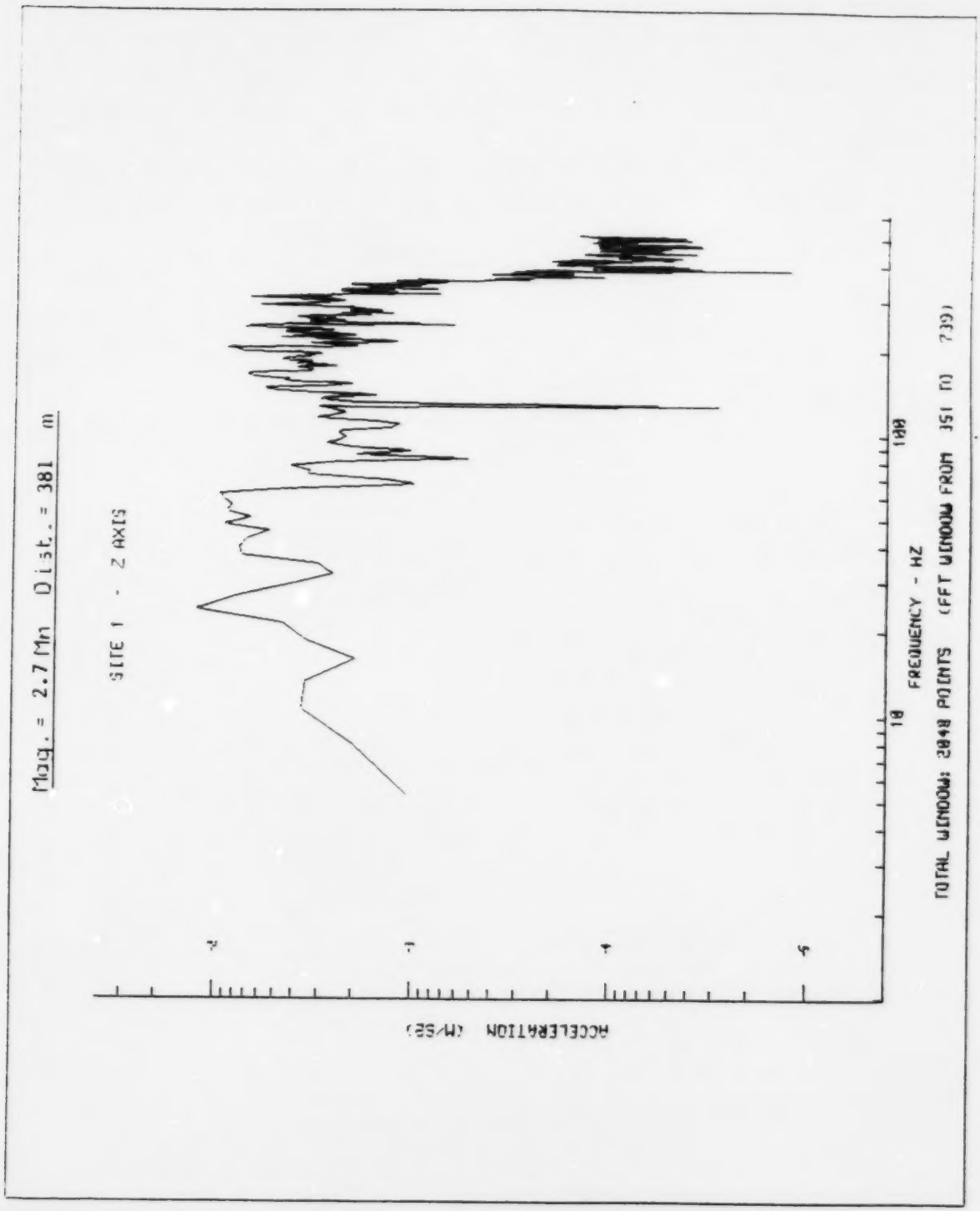

Fig. 4.8.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

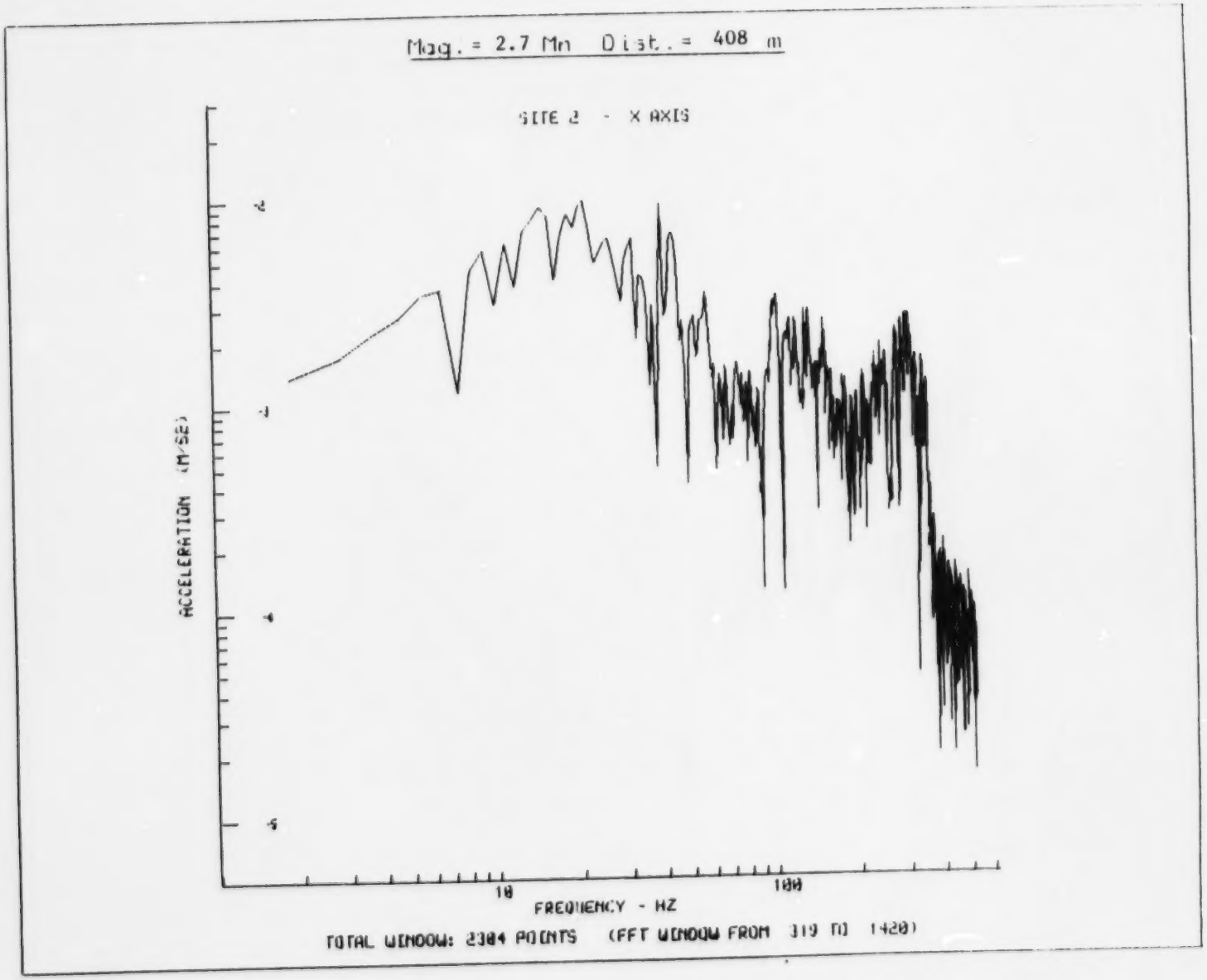

Fig. 4.9.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

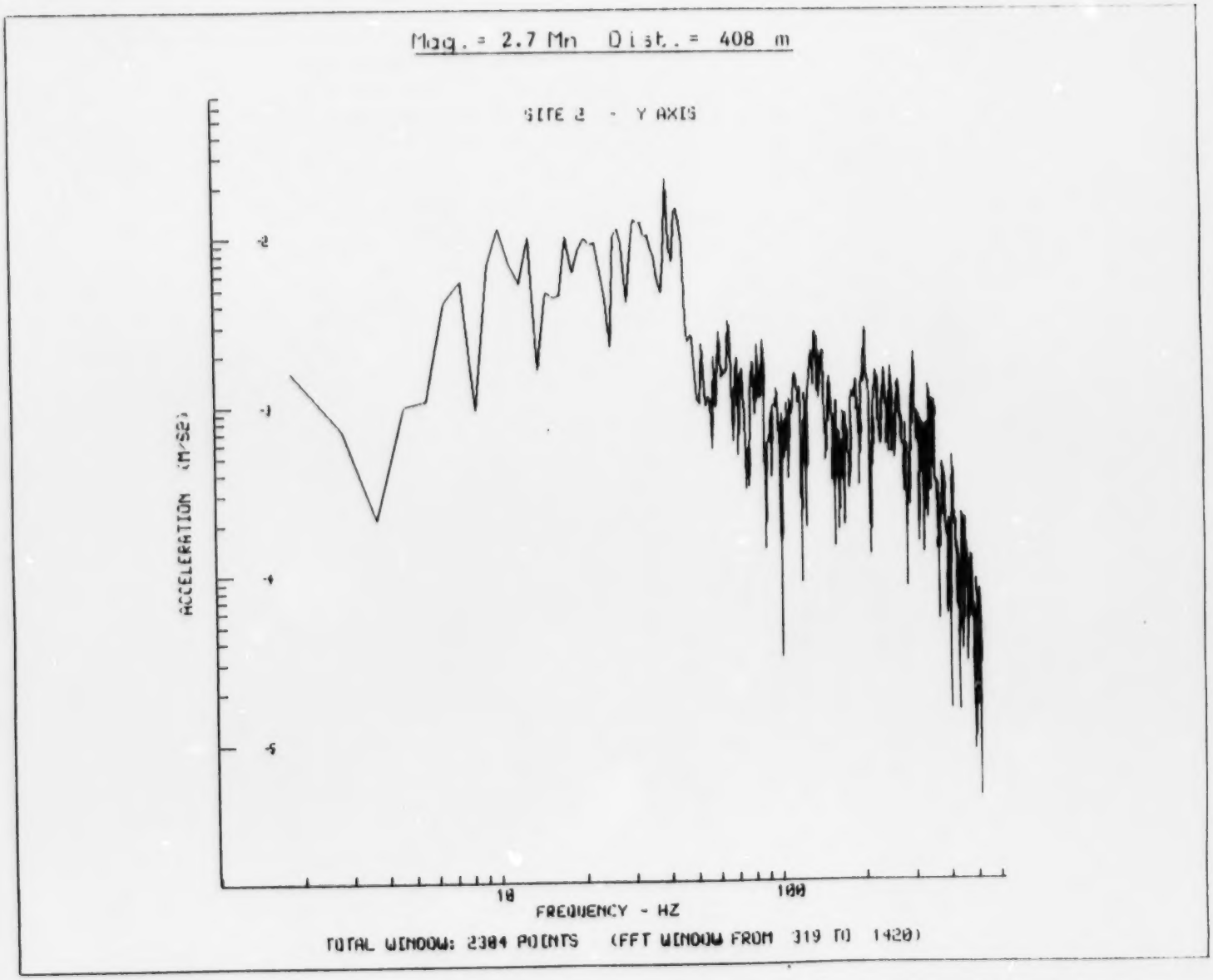

Fig. 4.9.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

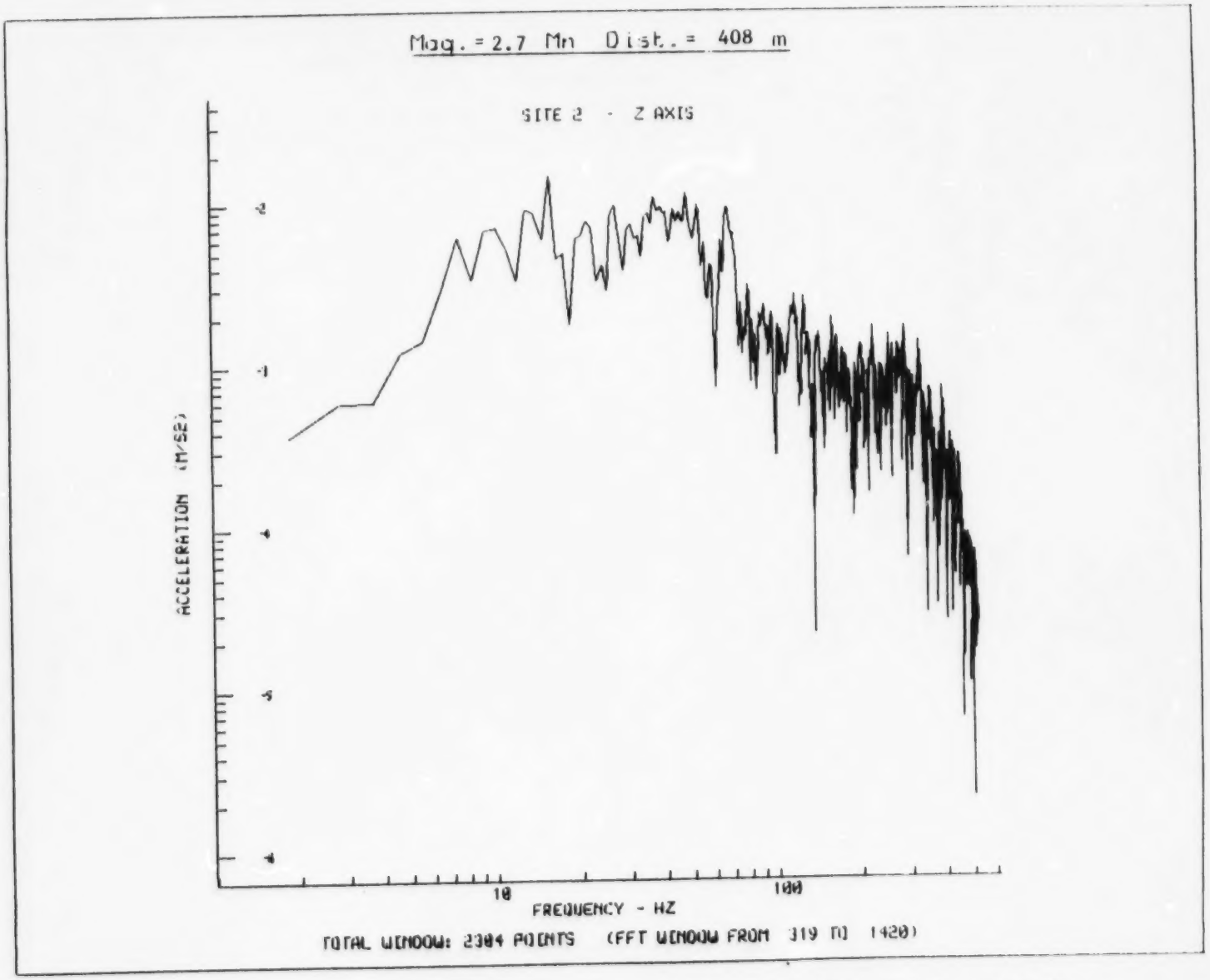

Fig. 4.9.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

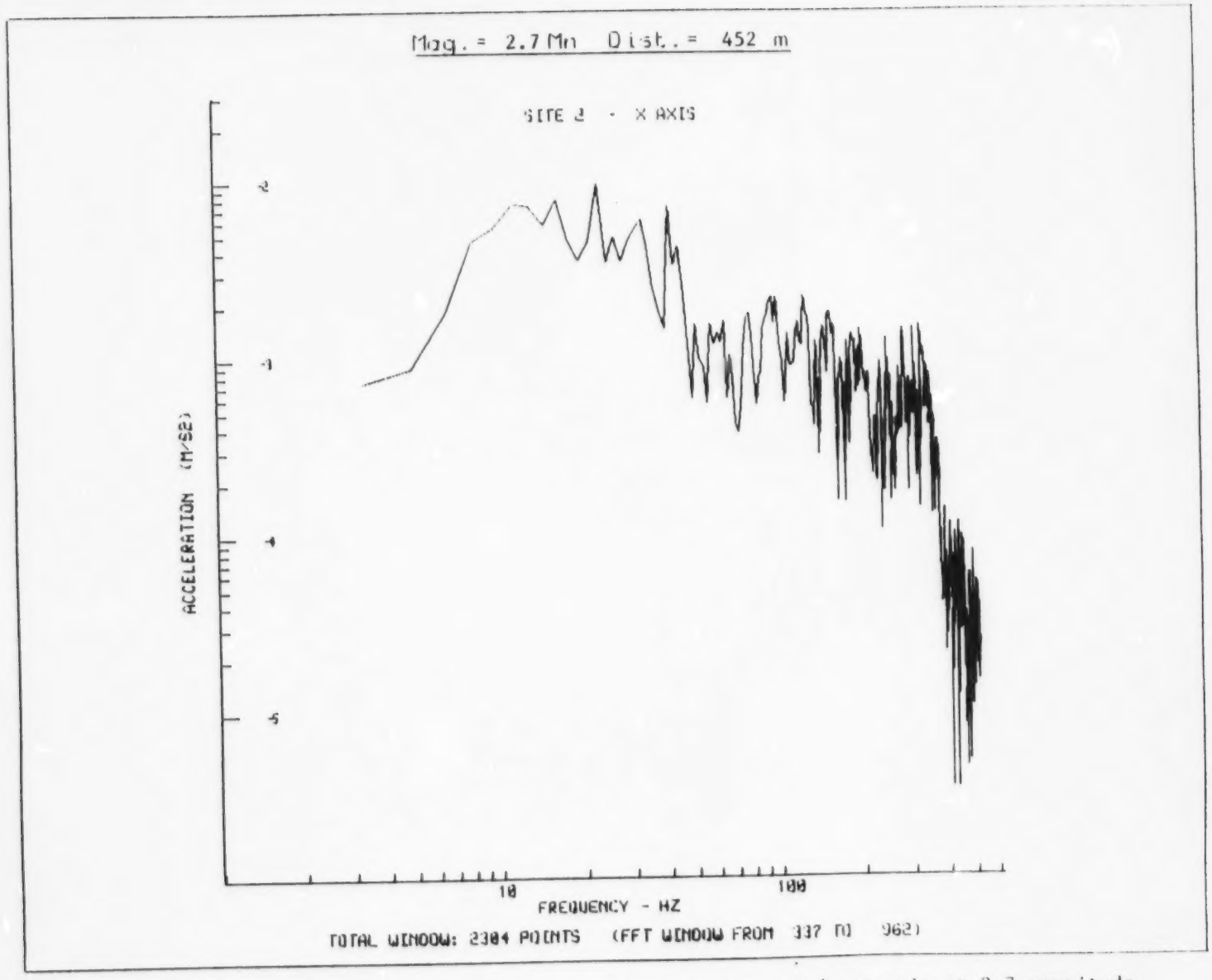

Fig. 4.10.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

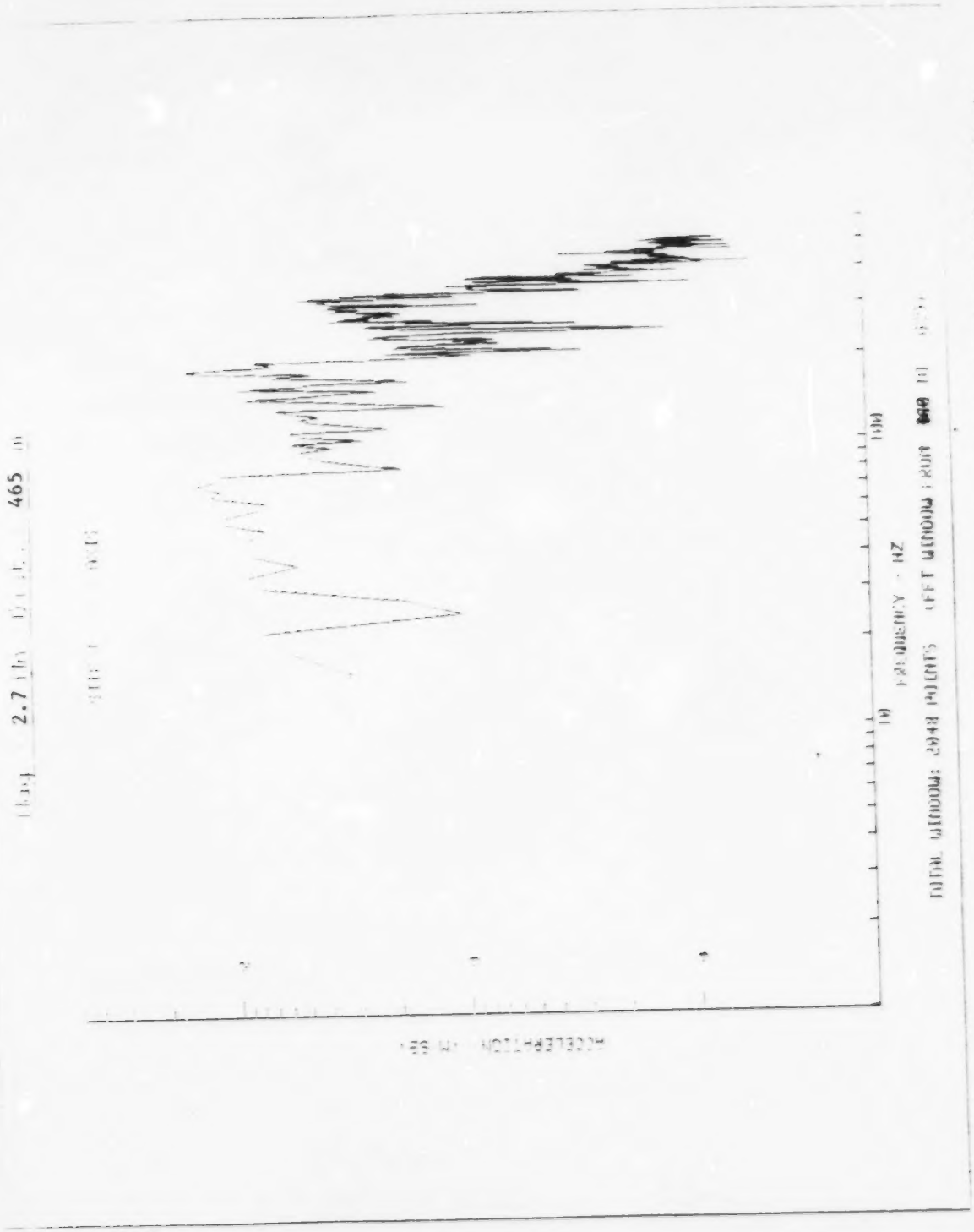

Fig.4.11.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

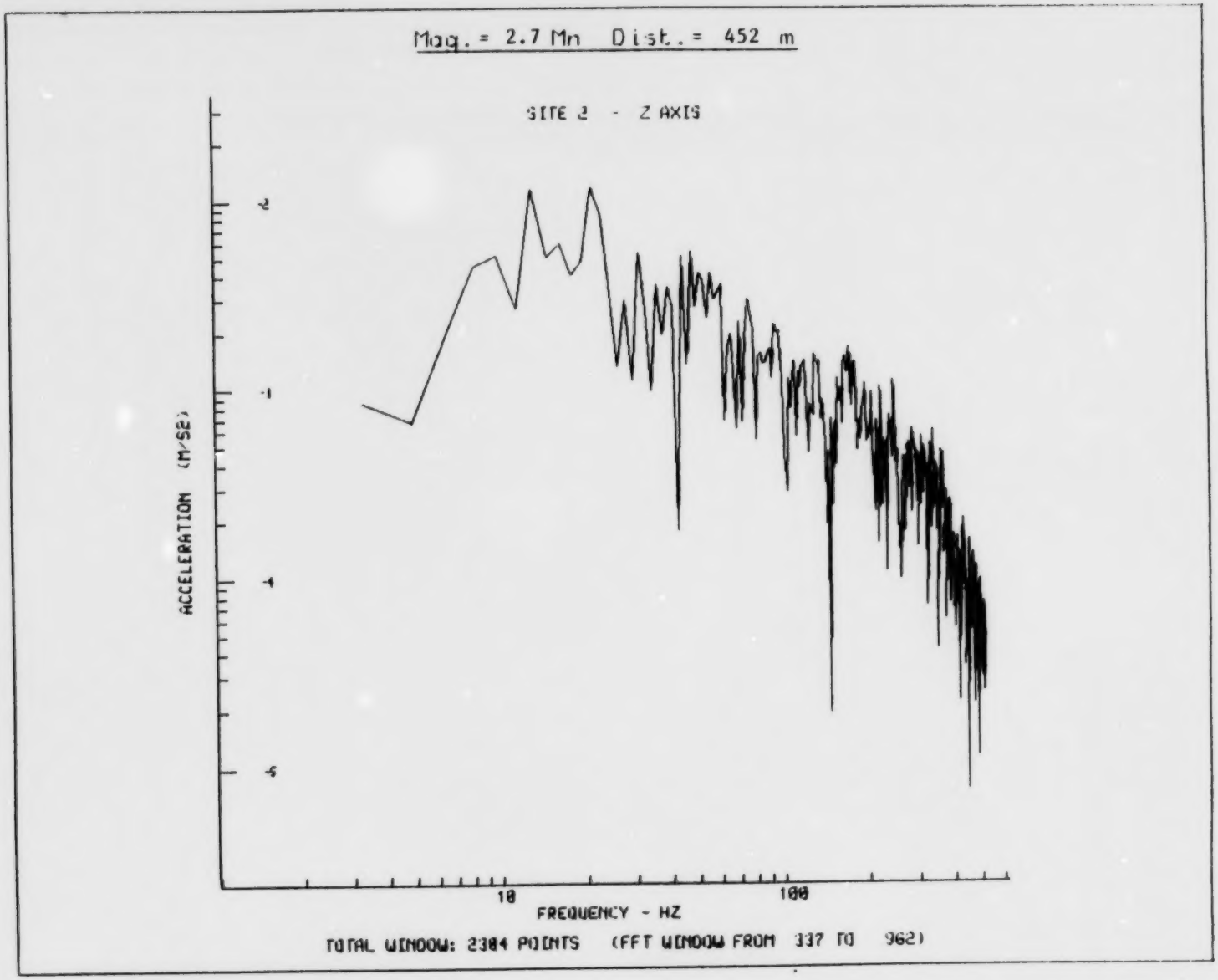

Fig. 4.10.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

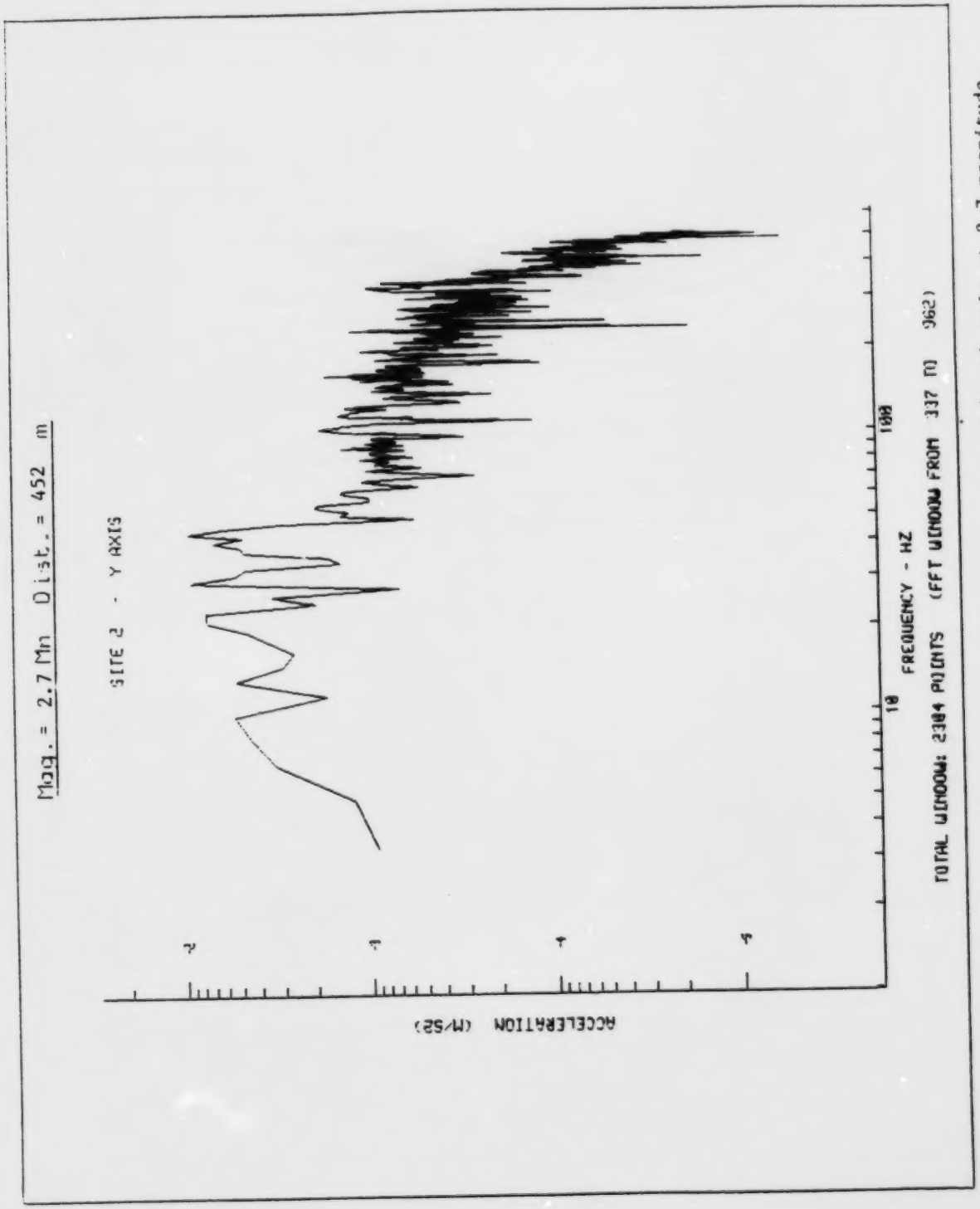

Fig. 4.10.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

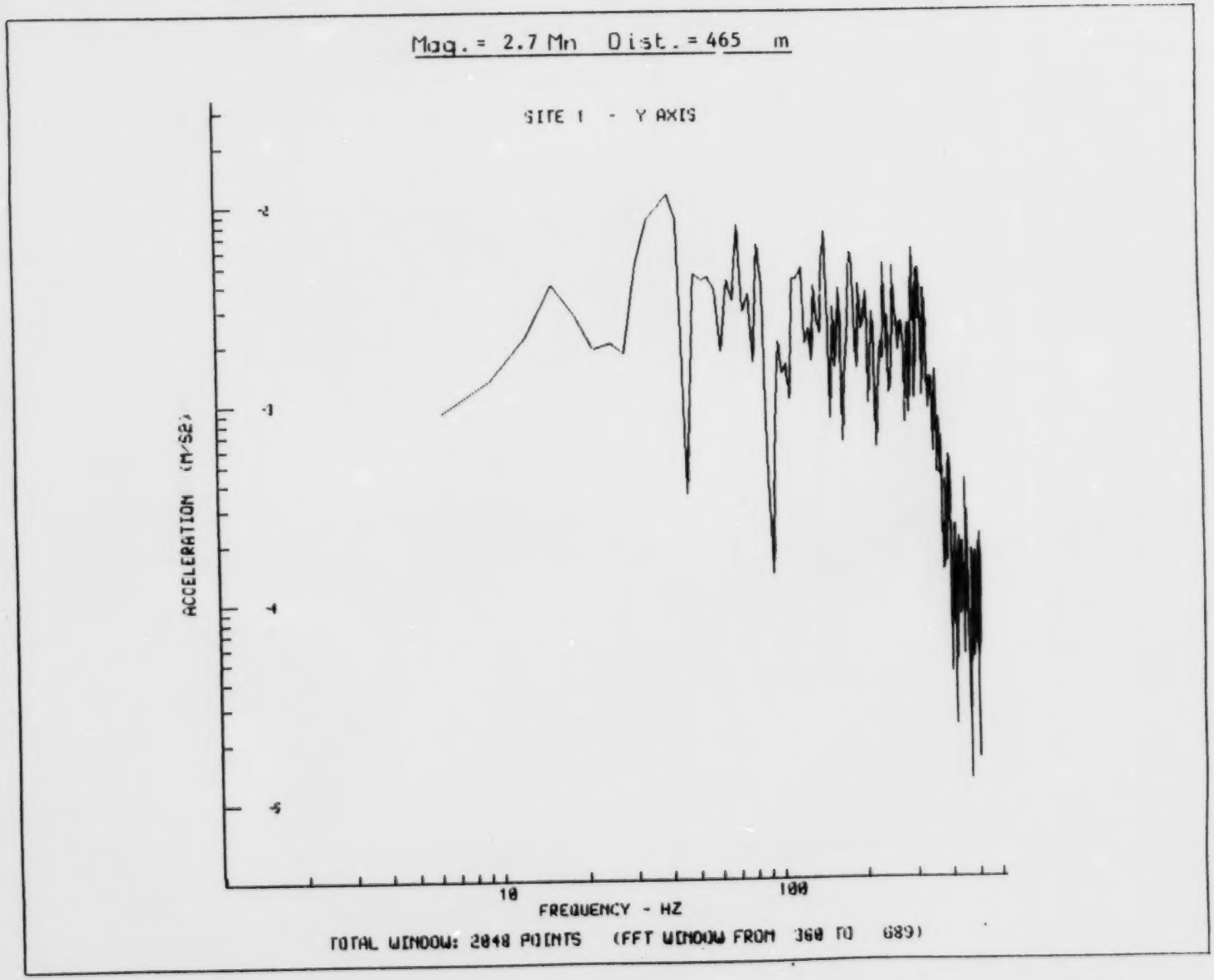

Fig. 4.11.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

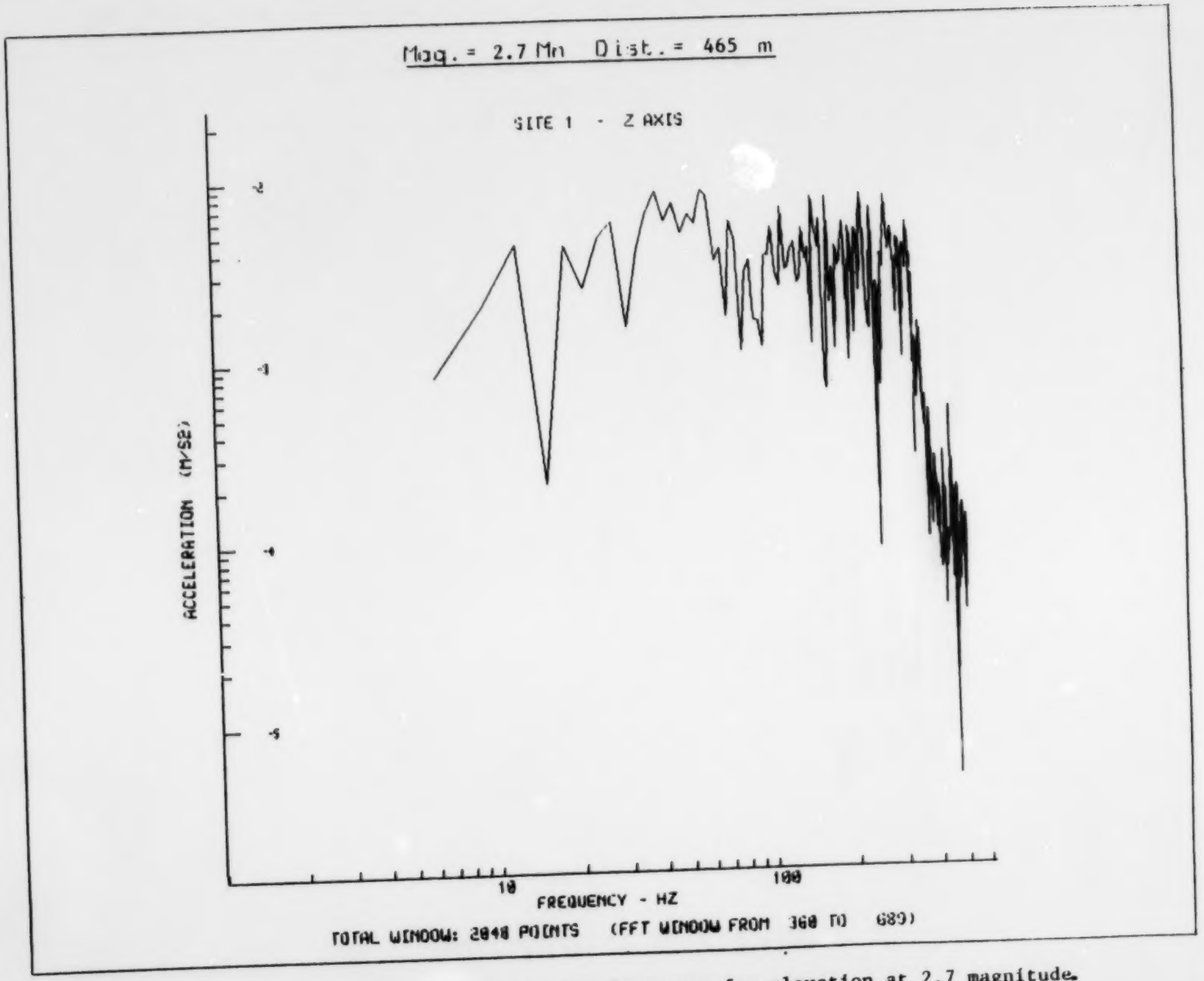

Fig. 4.11.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

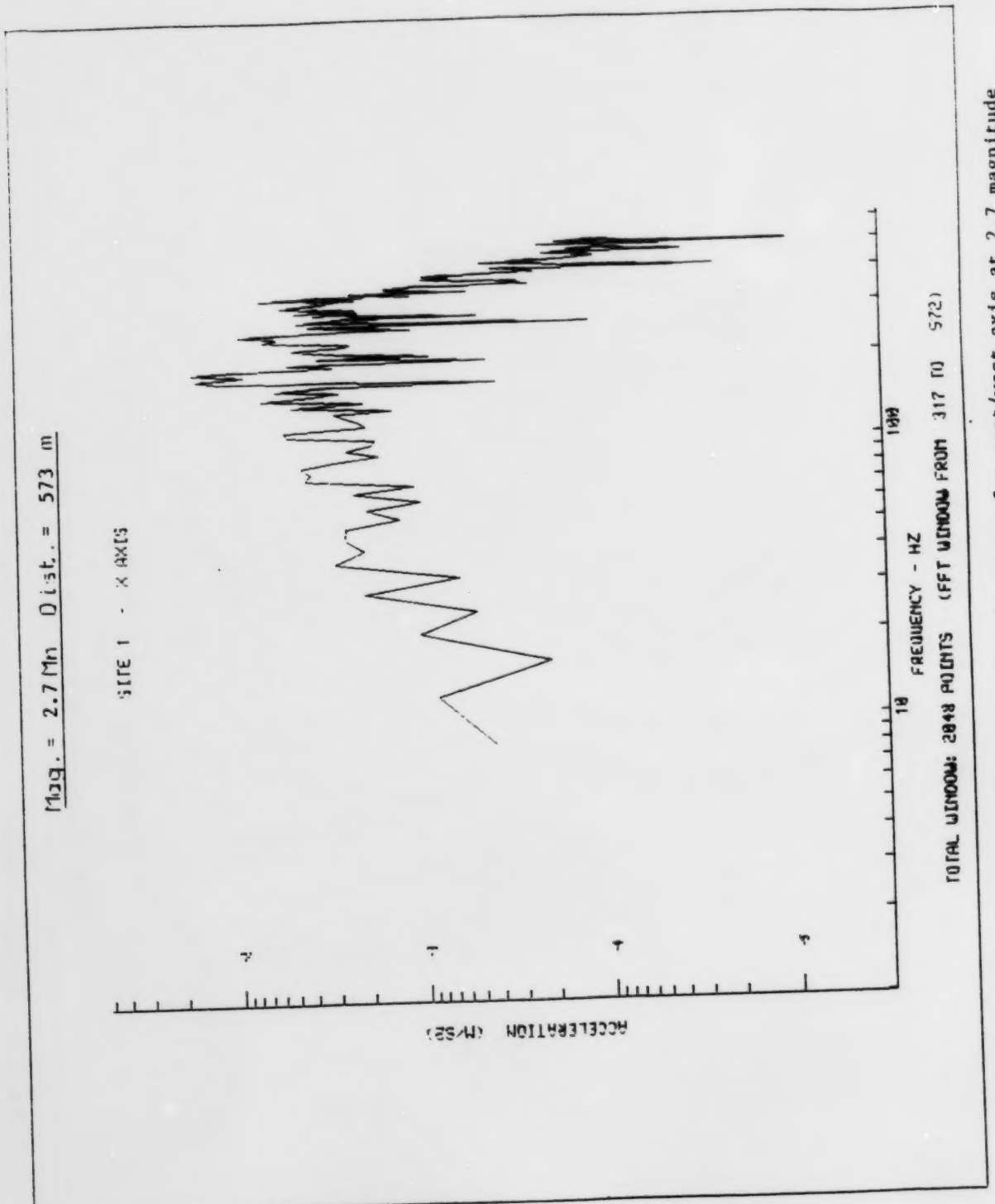

Fig. 4.12.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

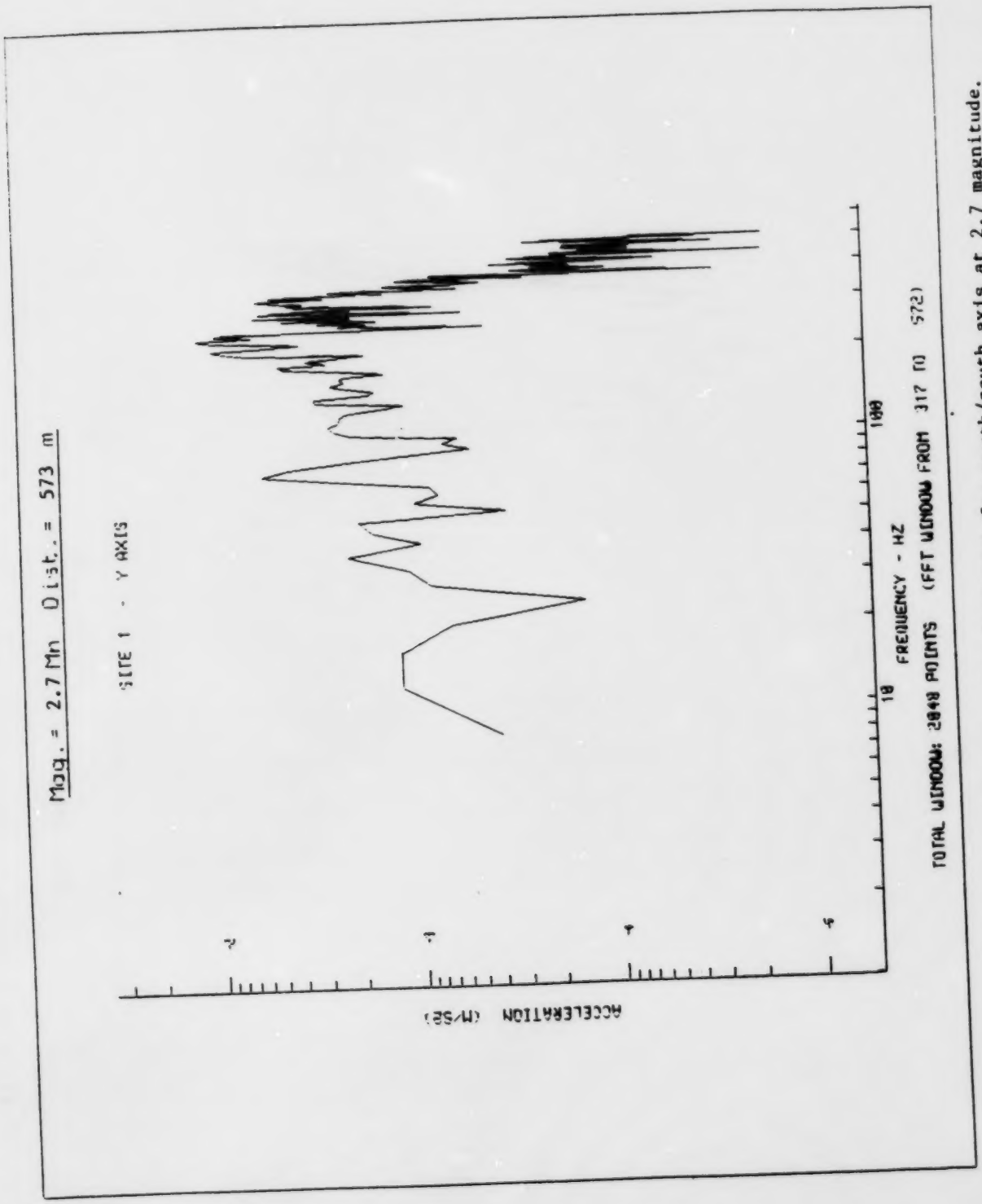

Fig.4.12.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

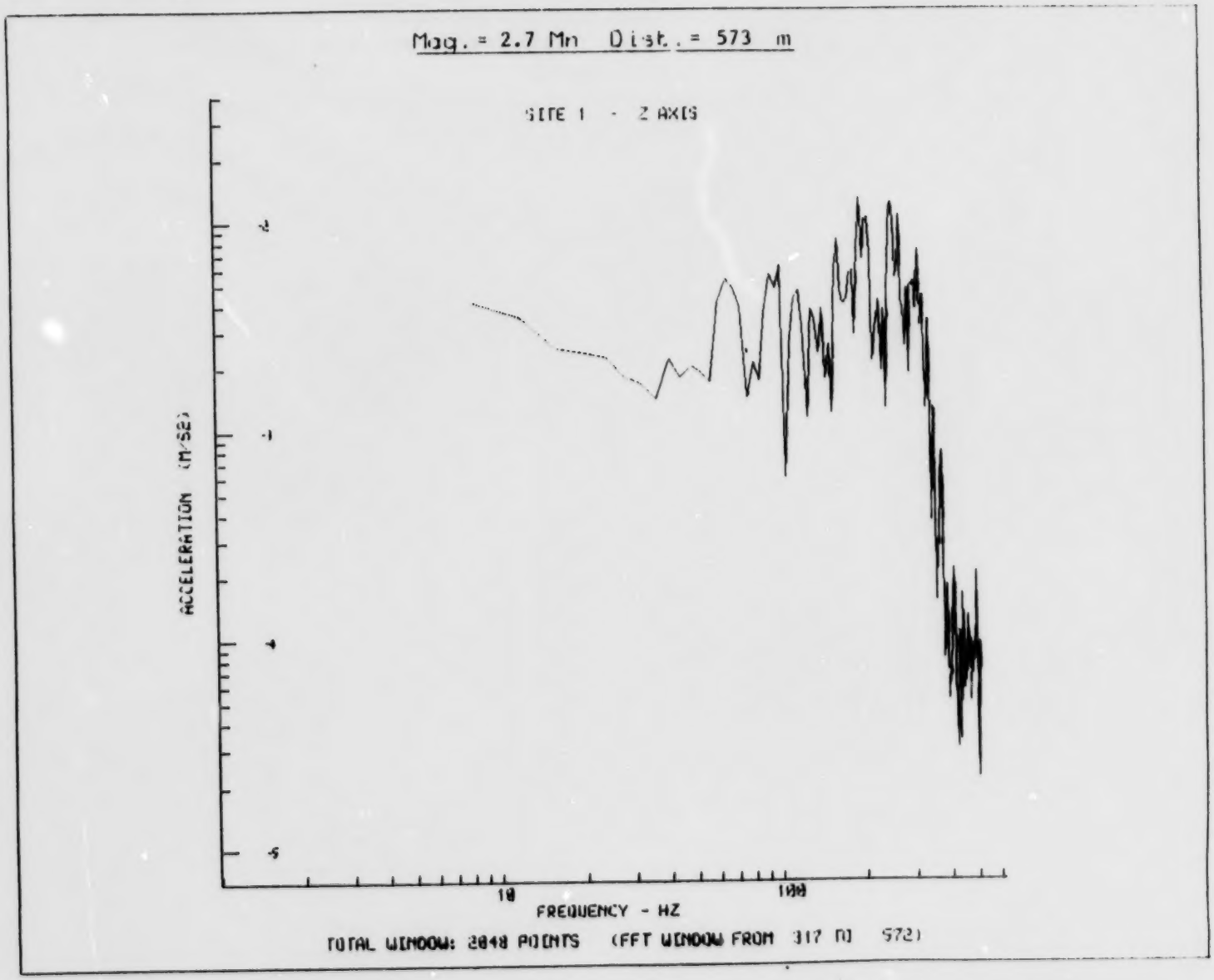

Fig. 4.12.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

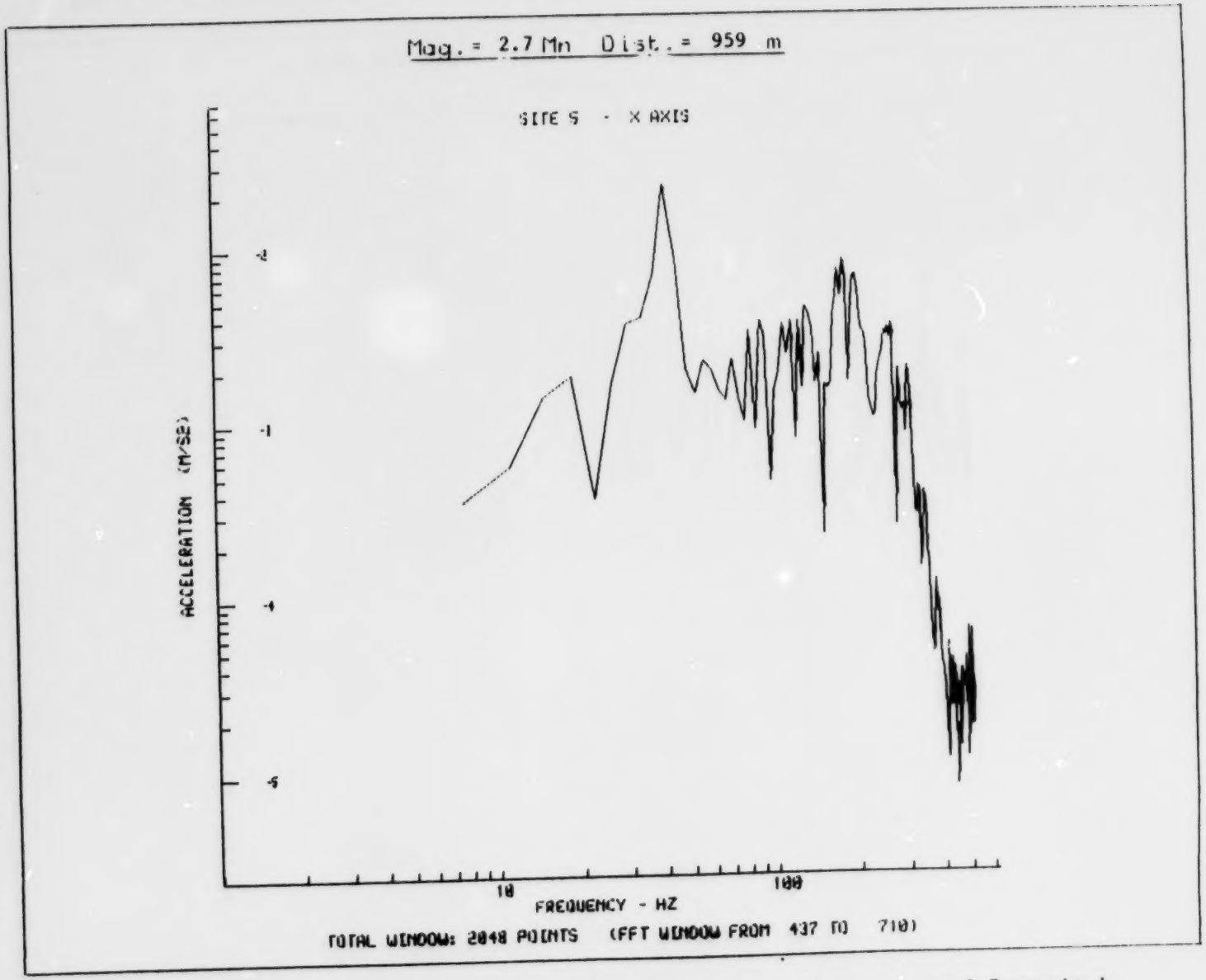

Fig. 4.13.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

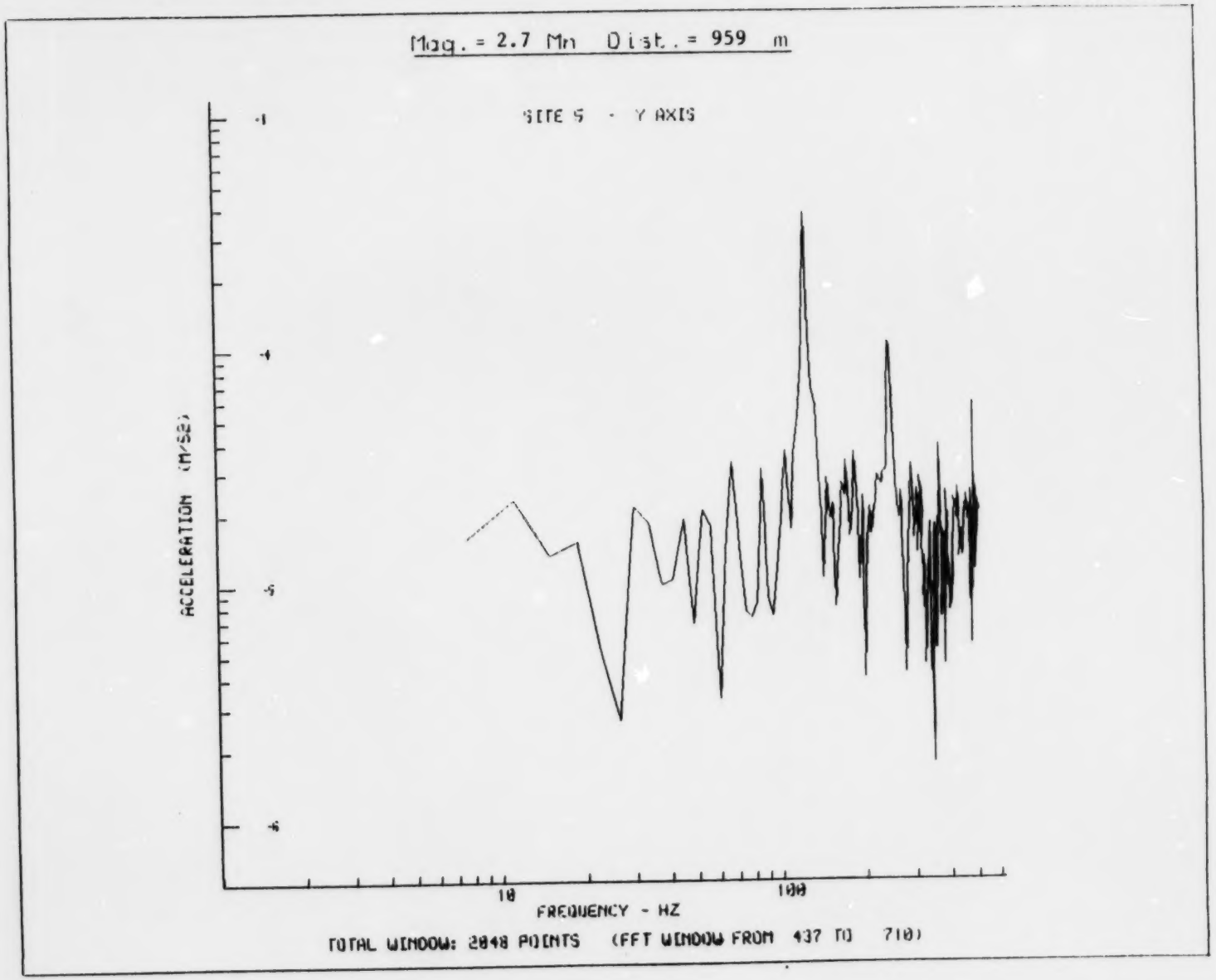

Fig. 4.13.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

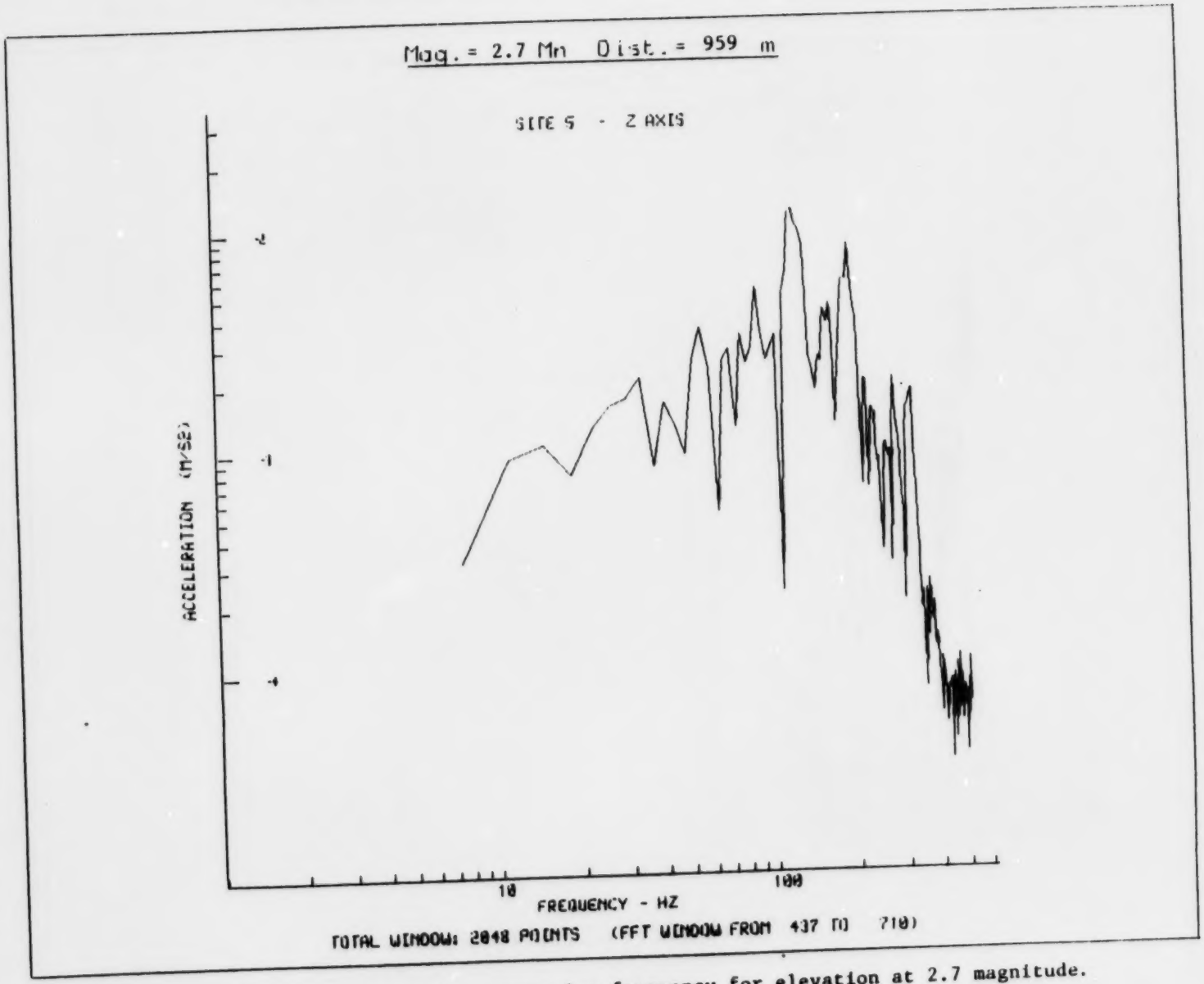

Fig. 4.13.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

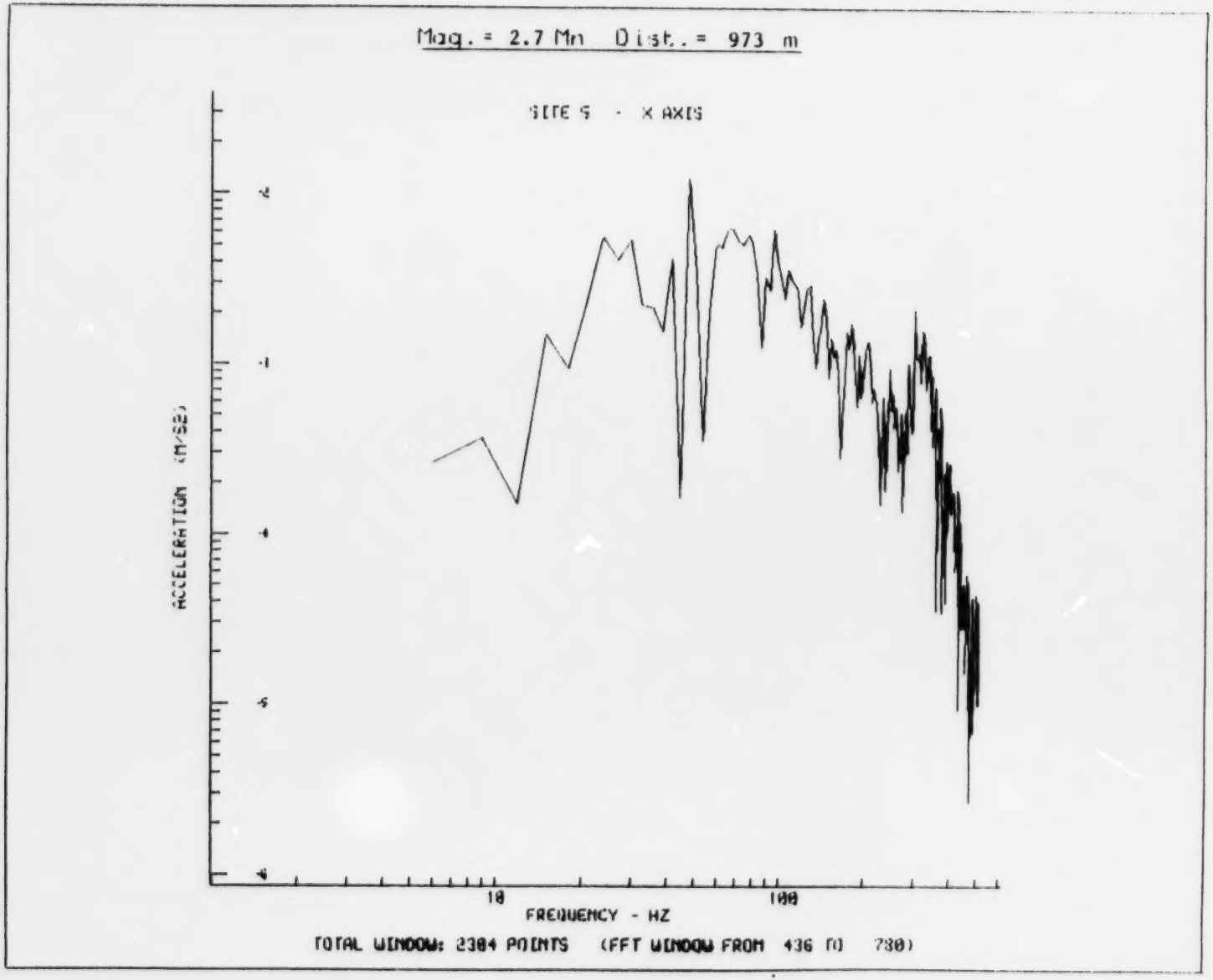

Fig. 4.14.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

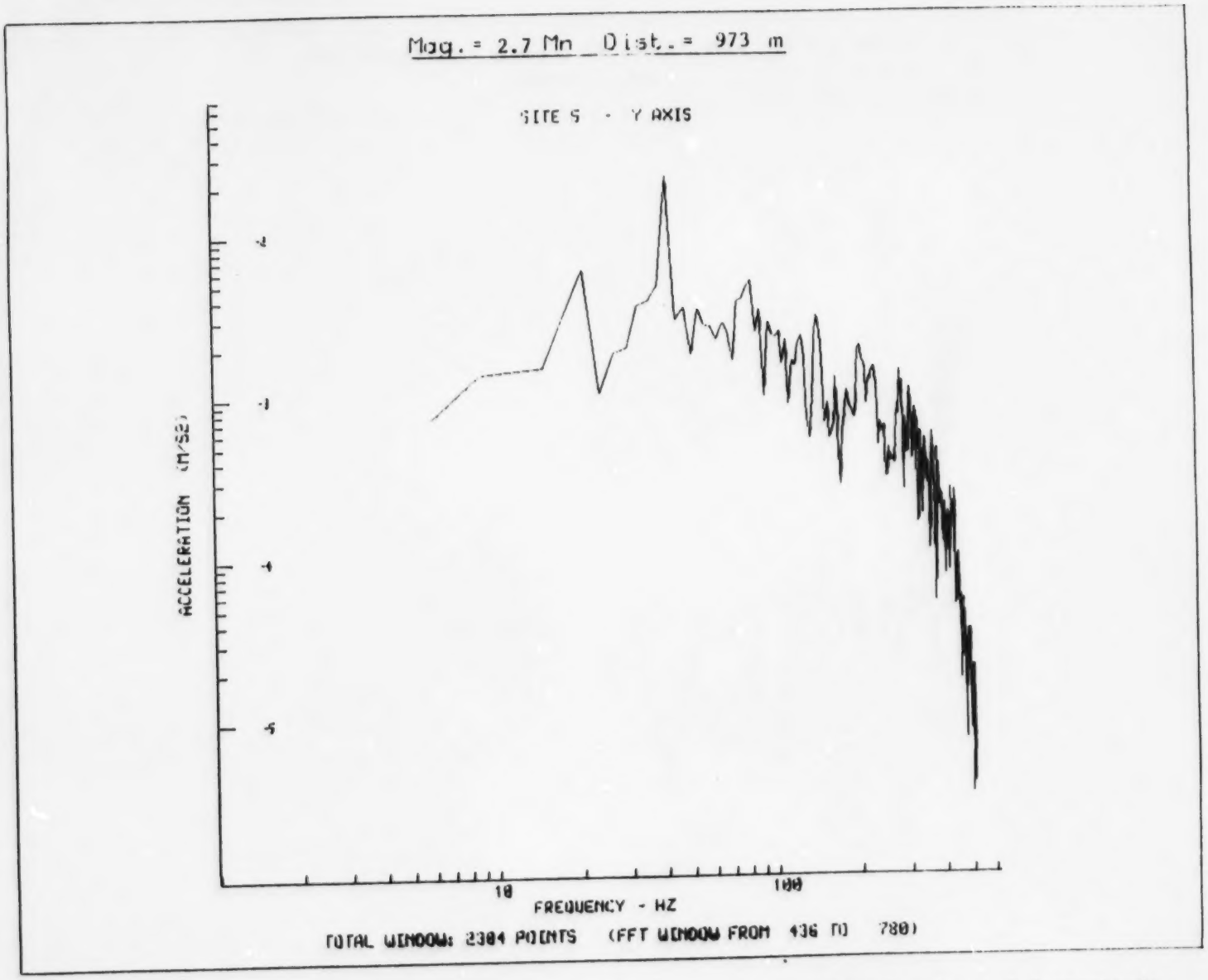

Fig. 4.14.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

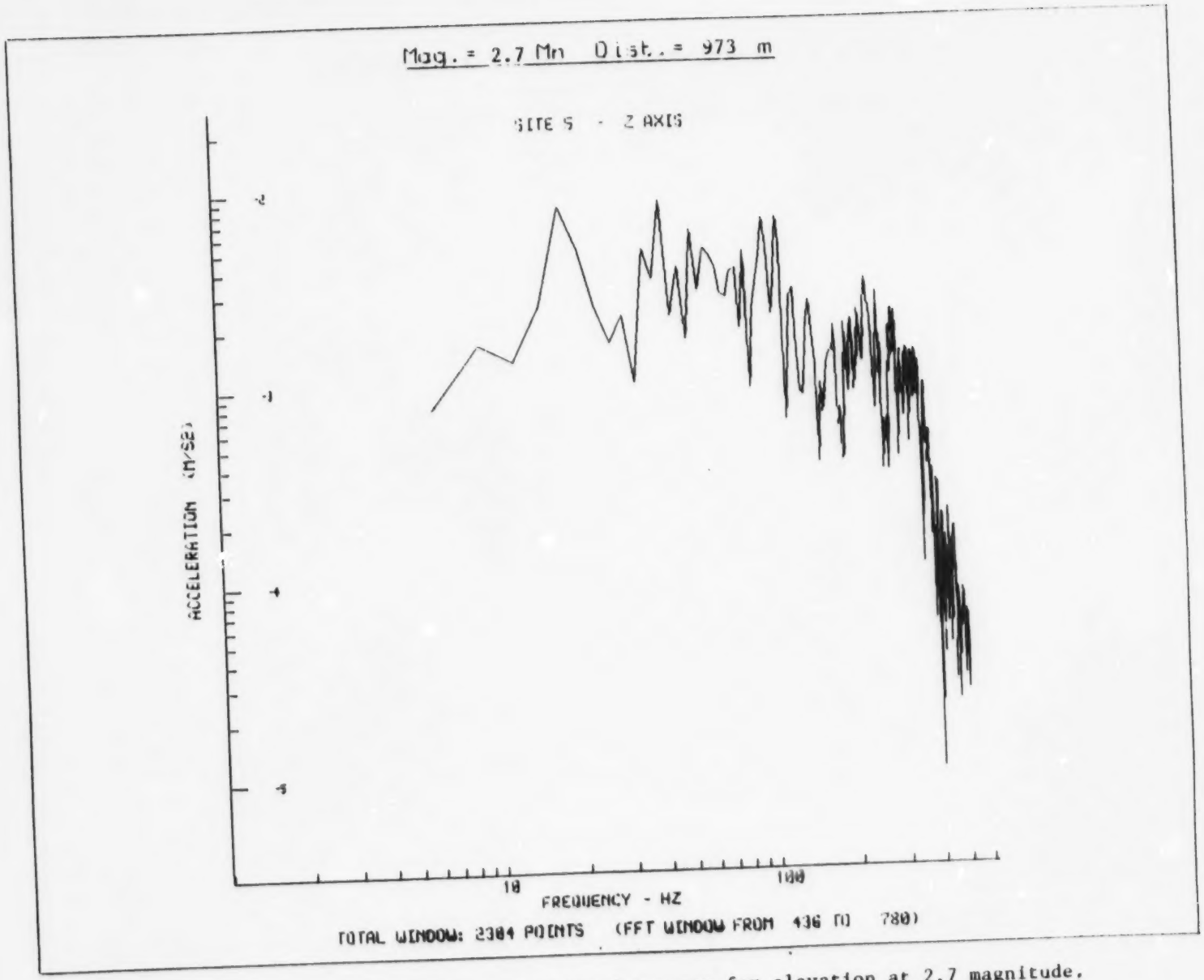

Fig.4.14.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

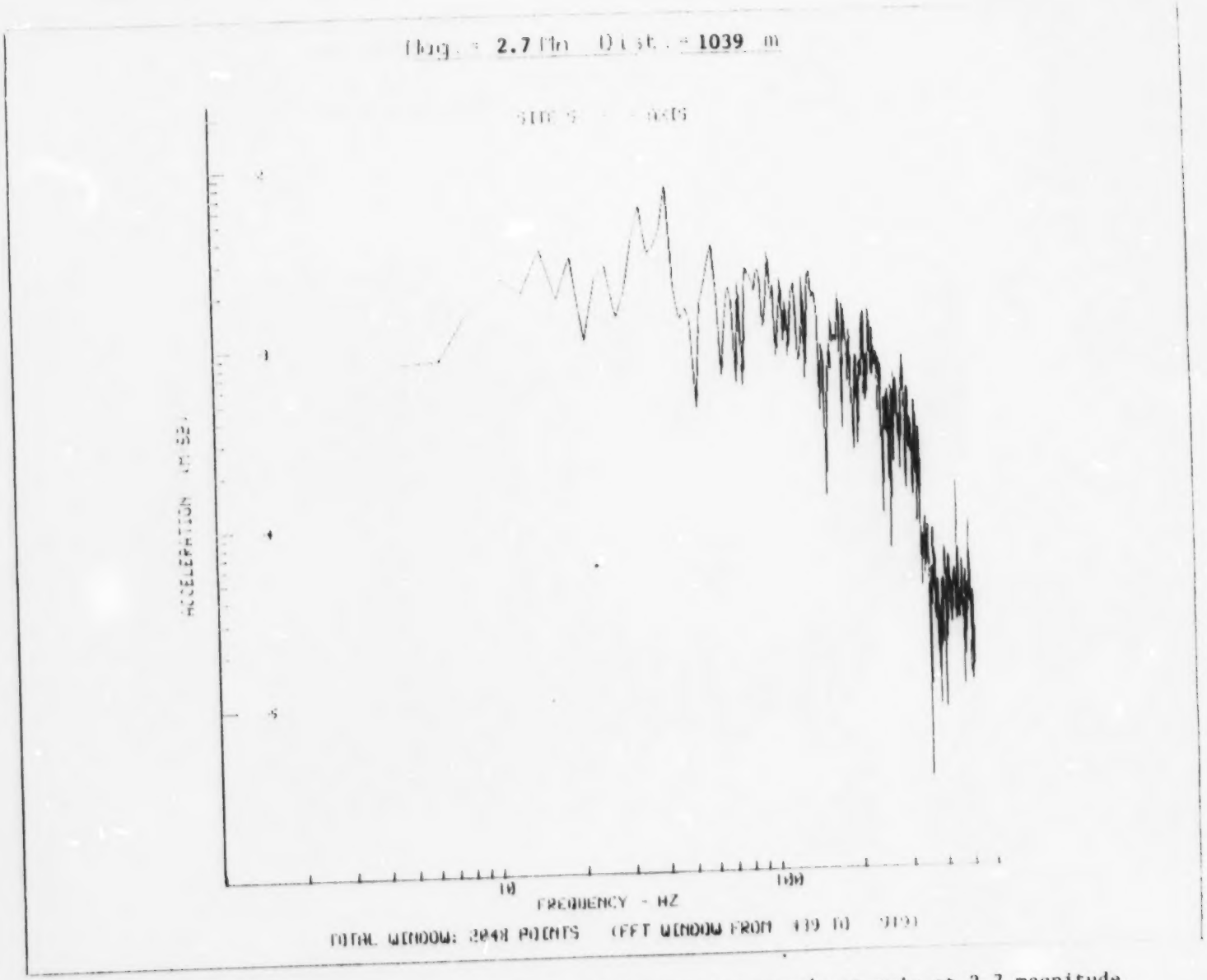

Fig. 4.15.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

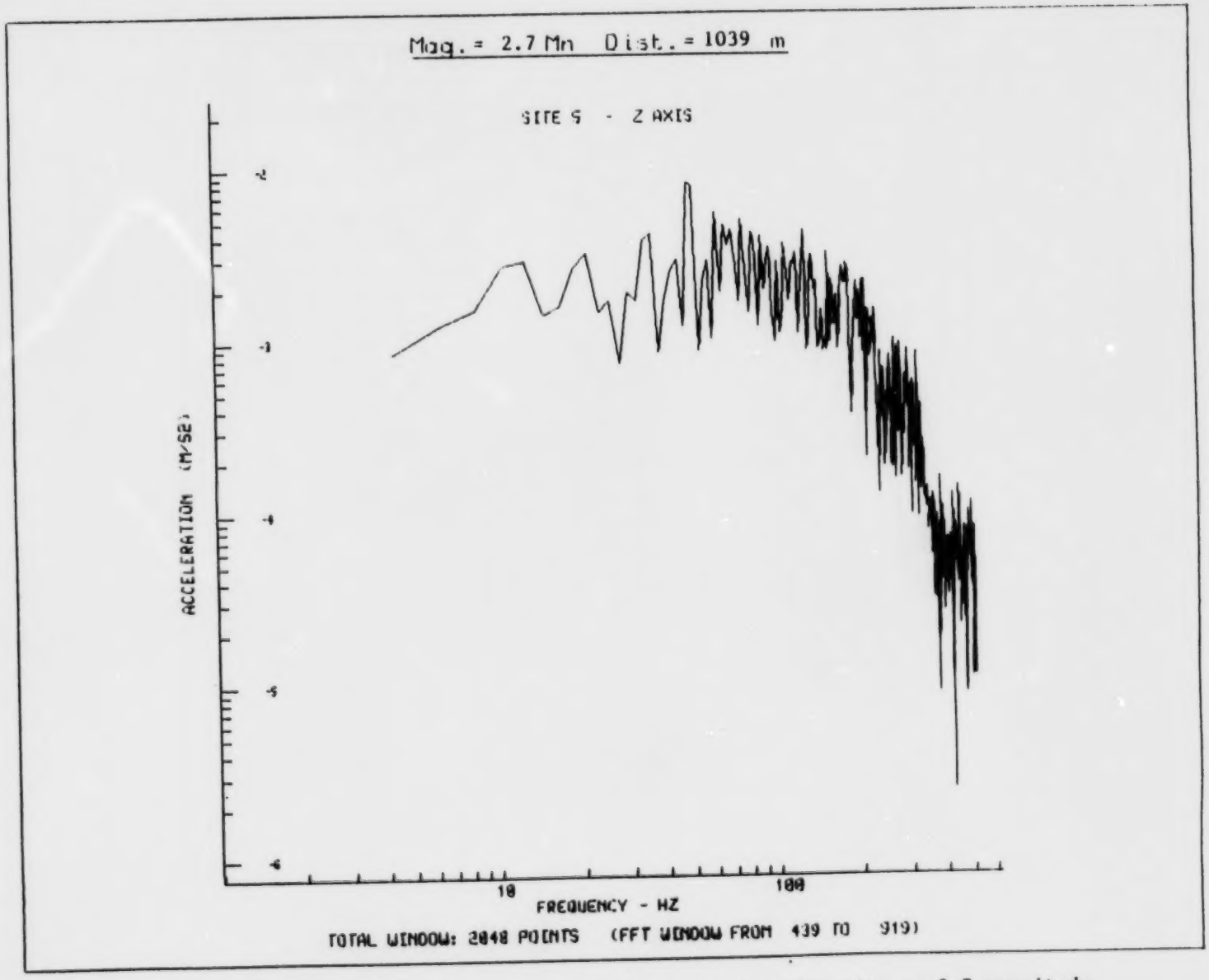

Fig. 4.15.2 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

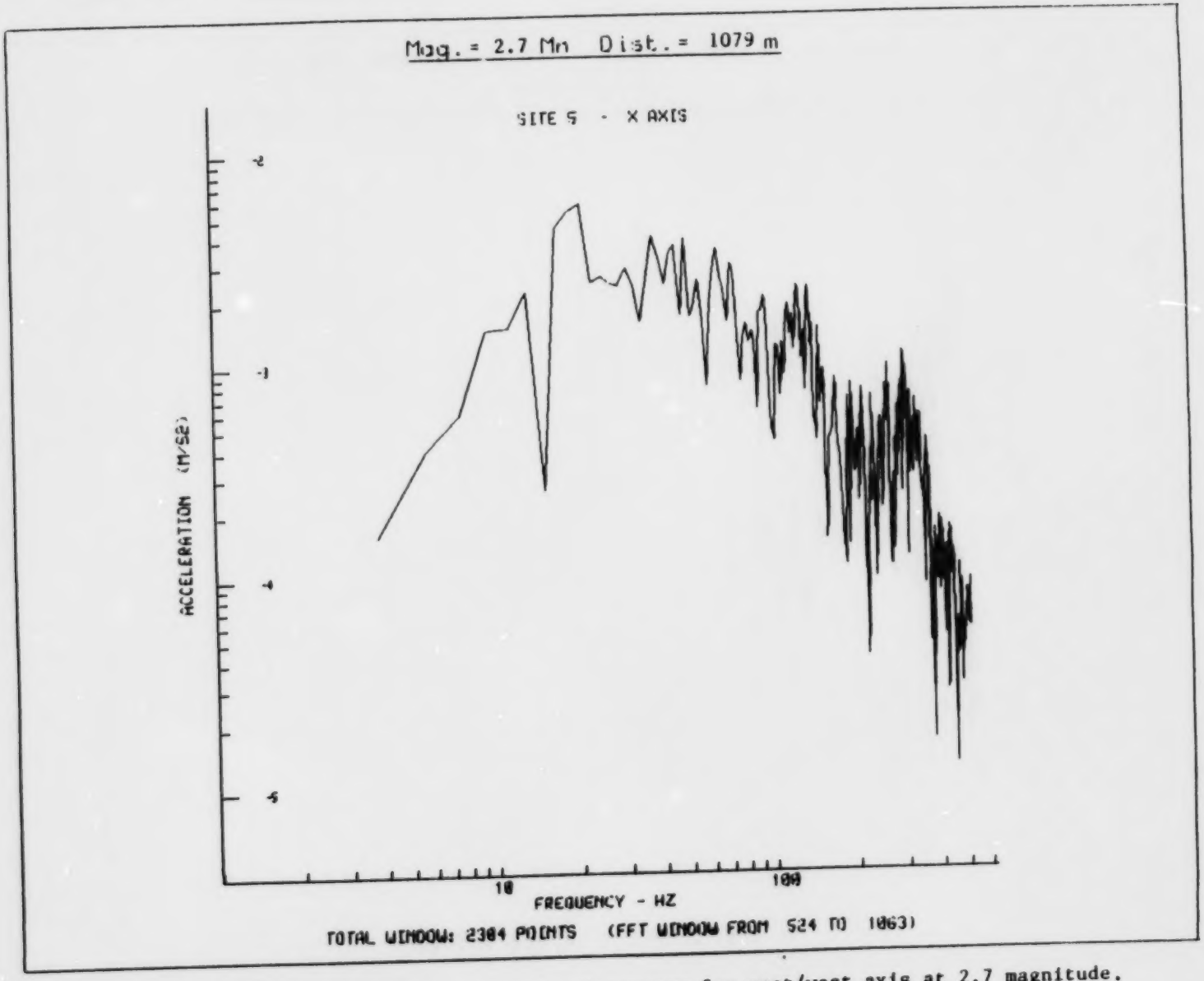

Fig.4.16.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

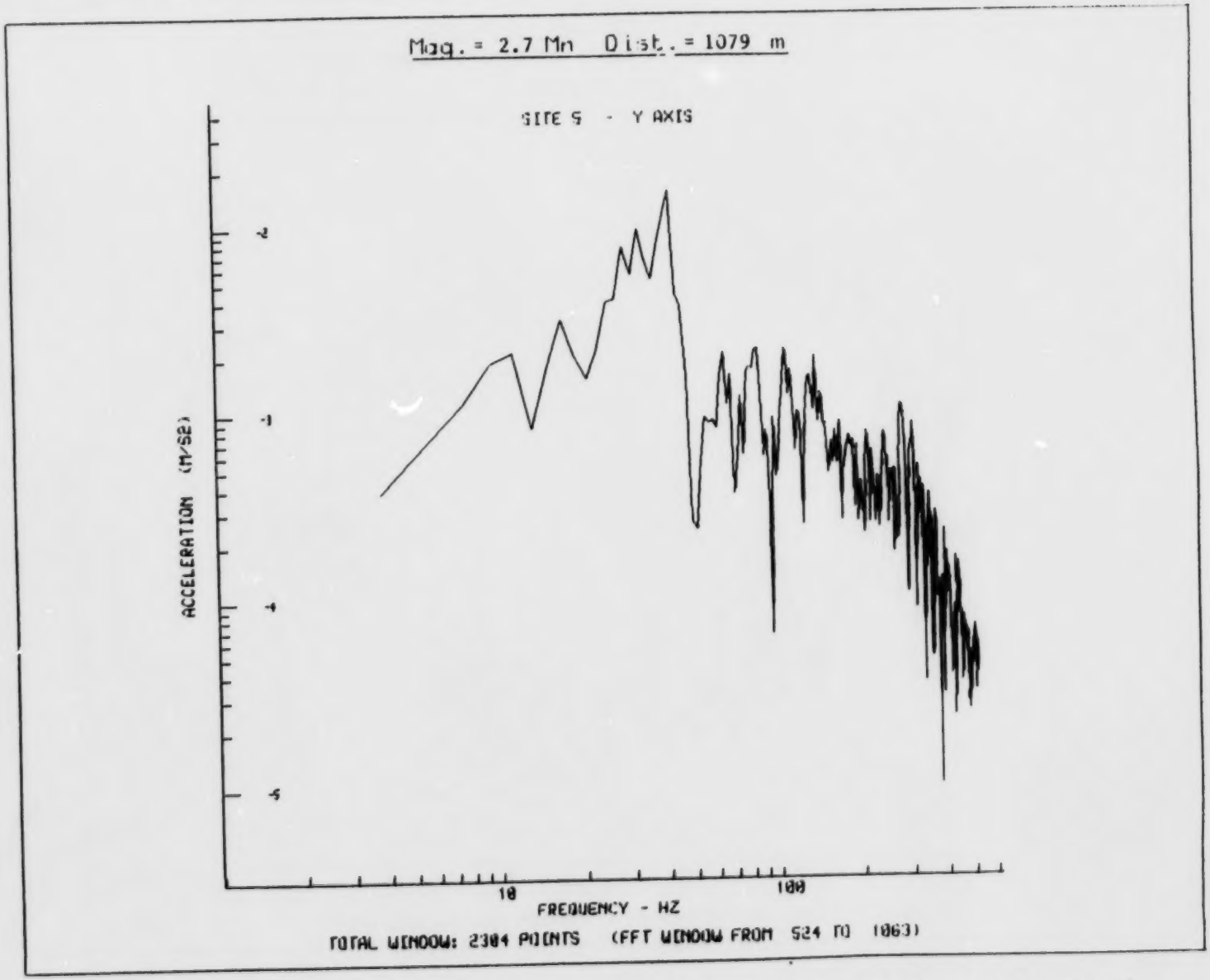

Fig. 4.16.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

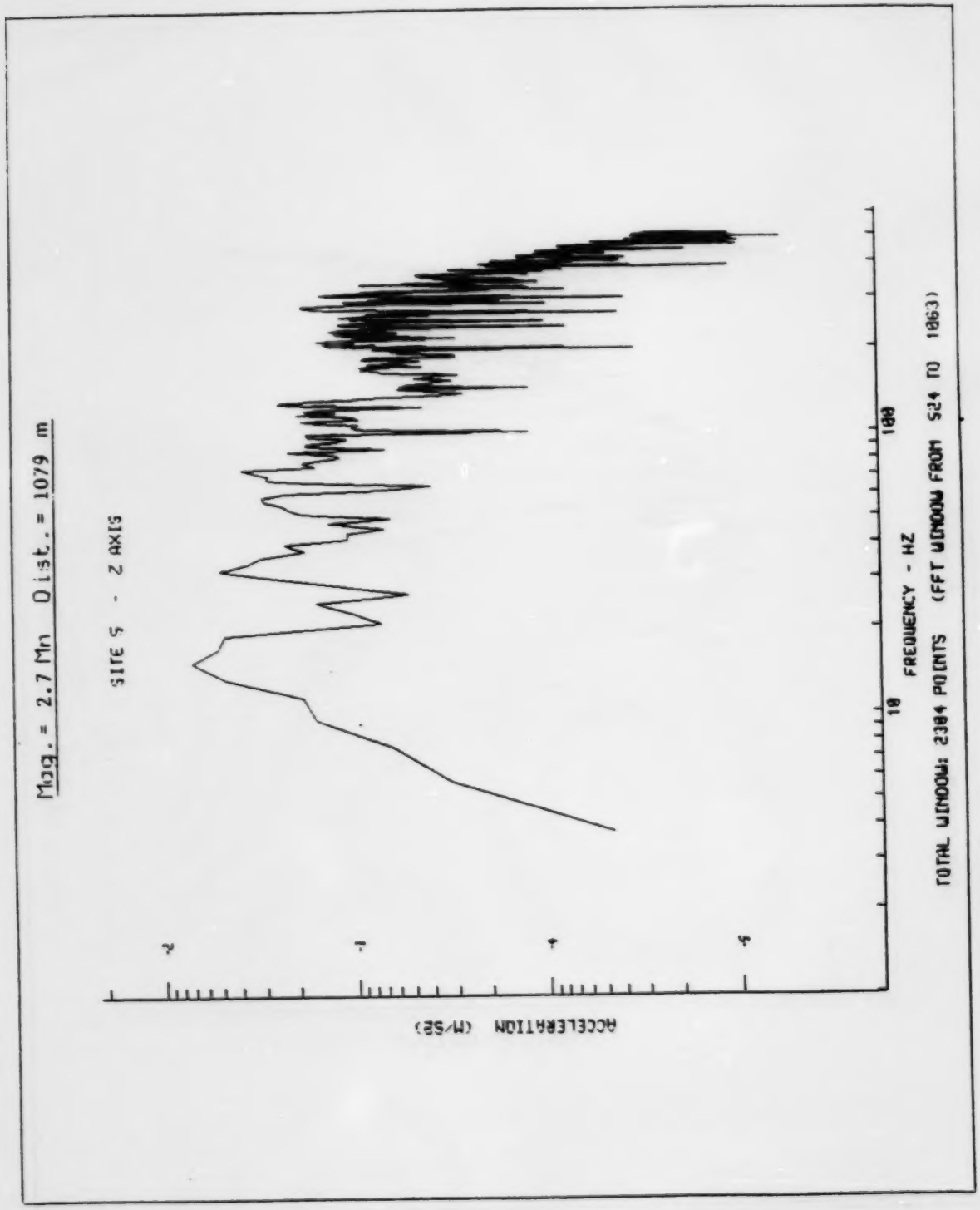

Fig.4.16.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

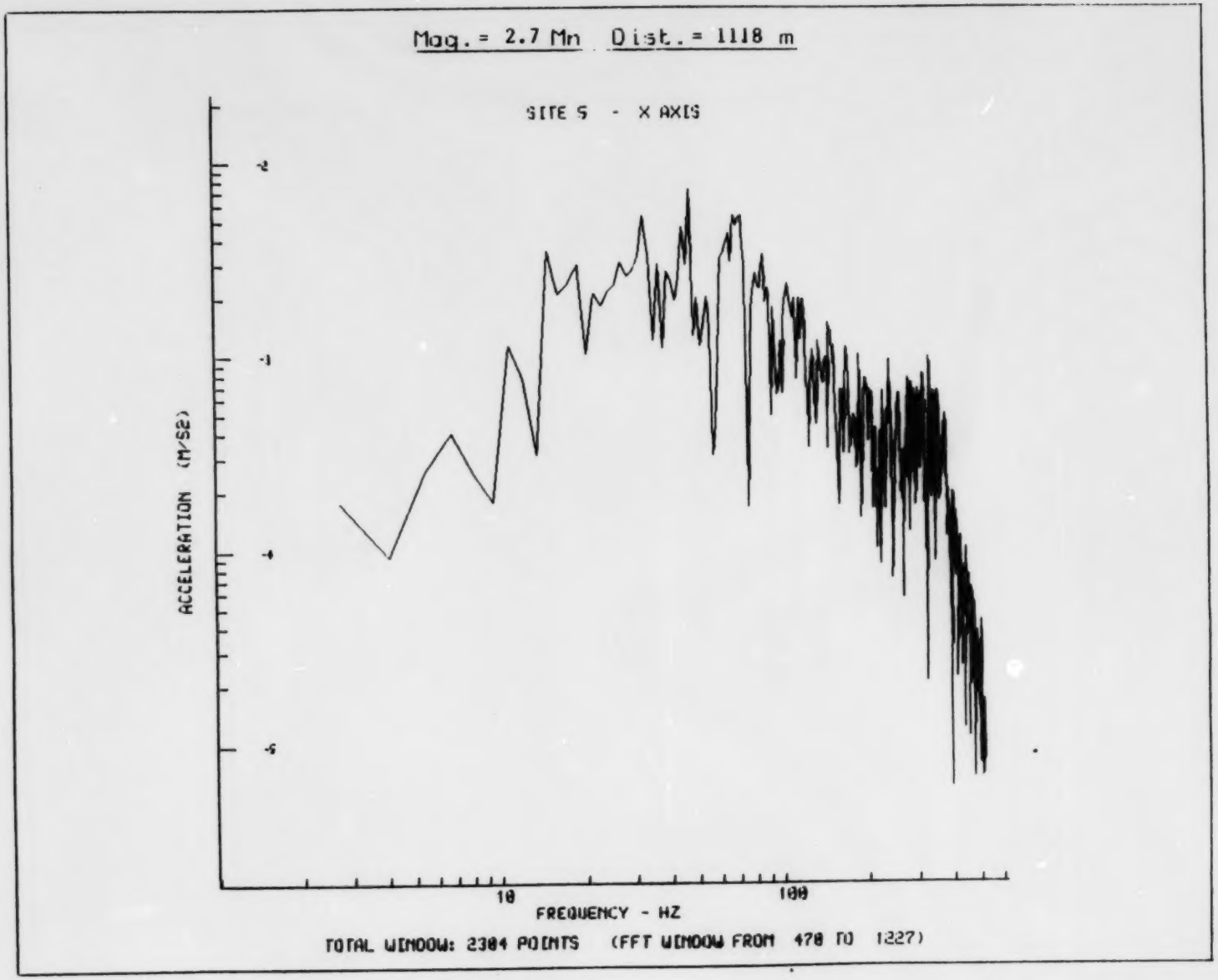

Fig. 4.17.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

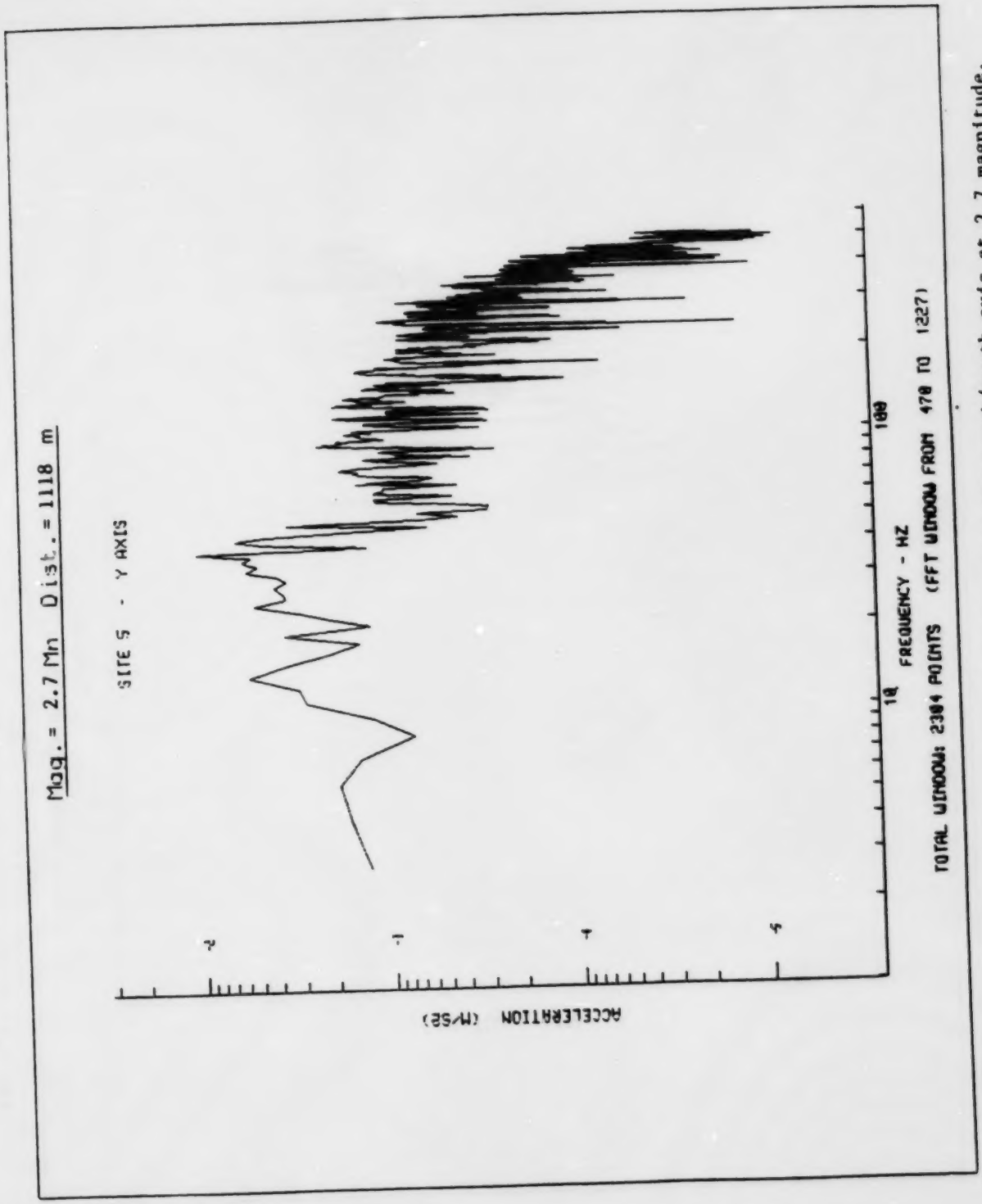

Fig.4.17.2 – Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

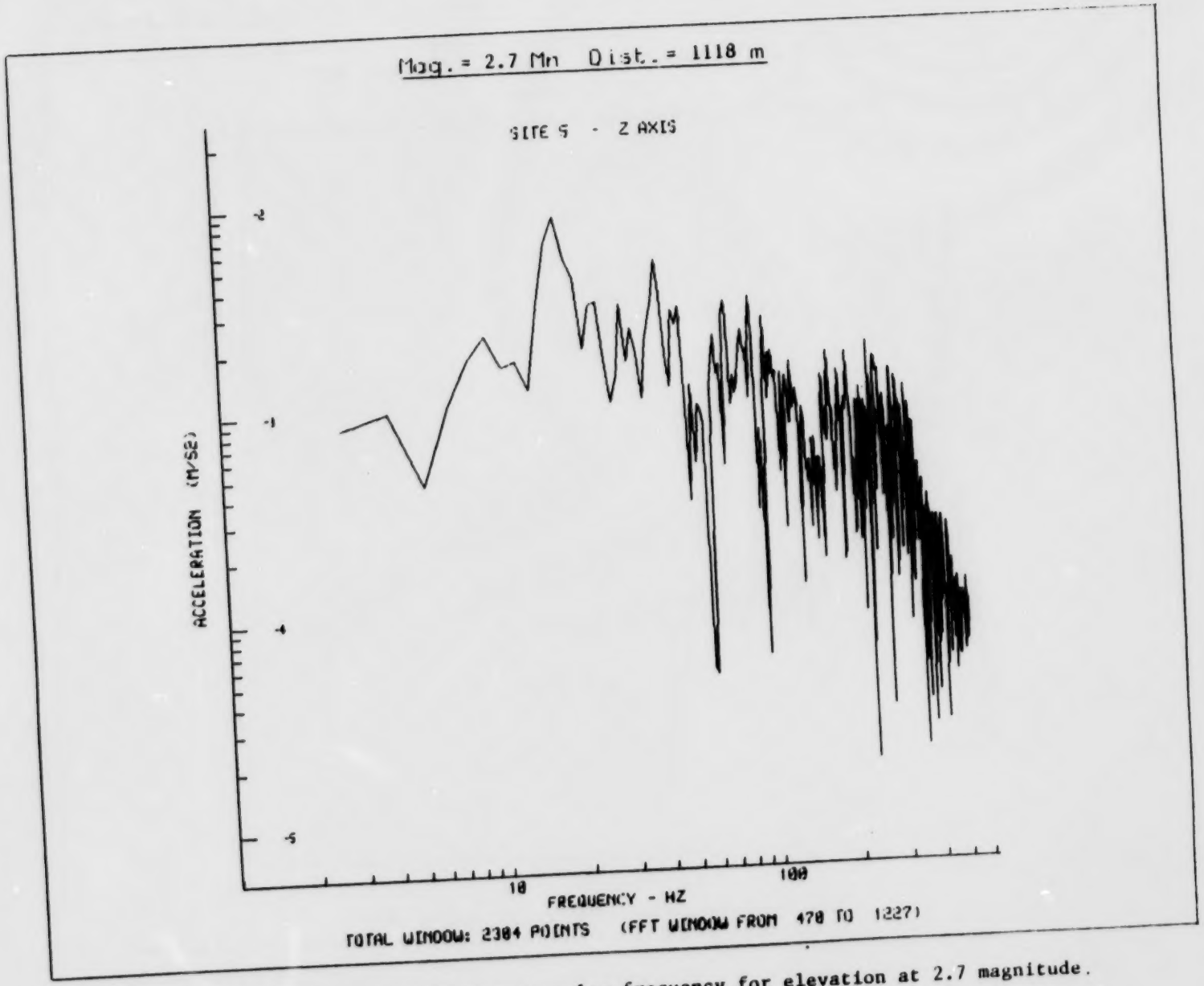

Fig. 4.17.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

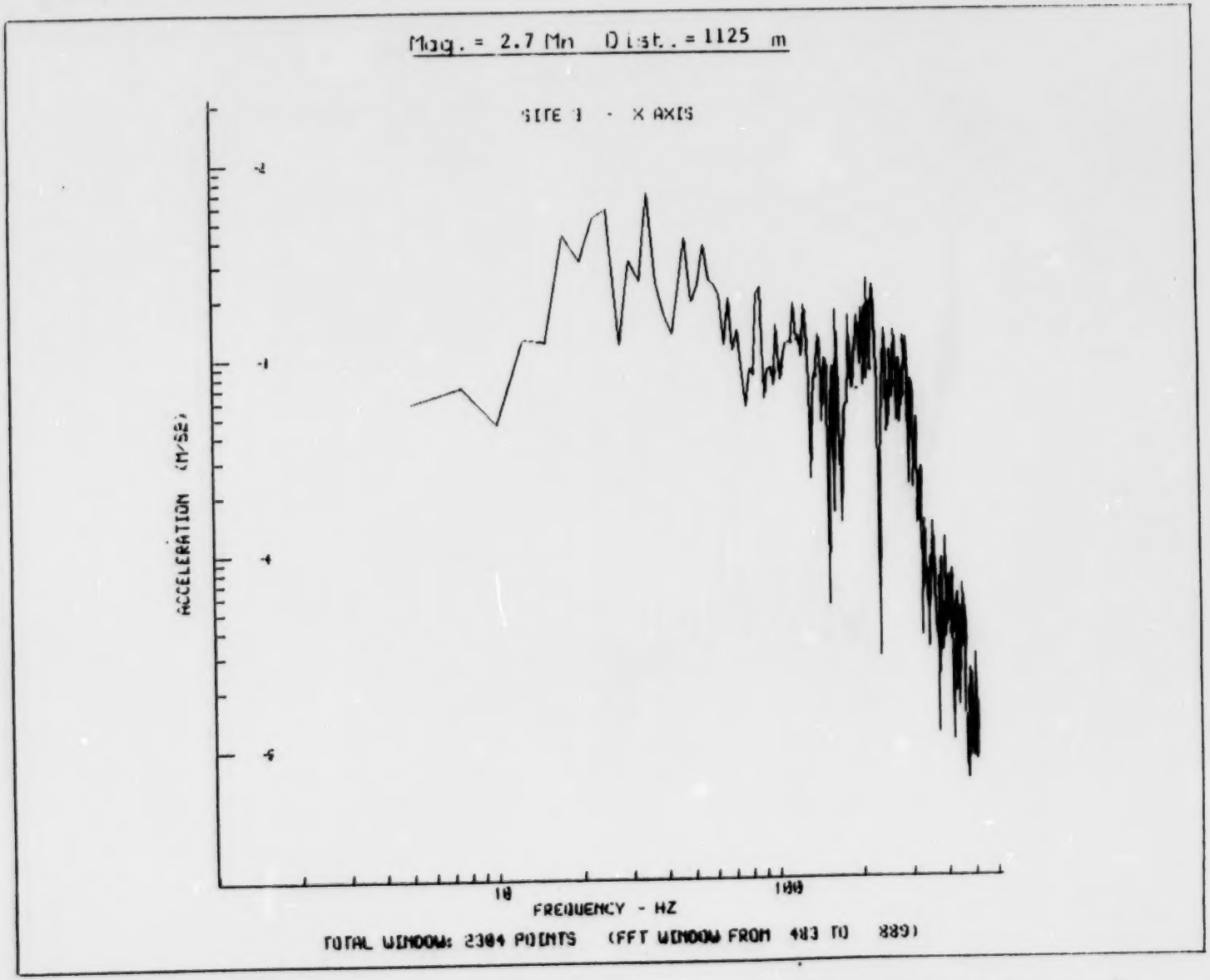

Fig. 4.18.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

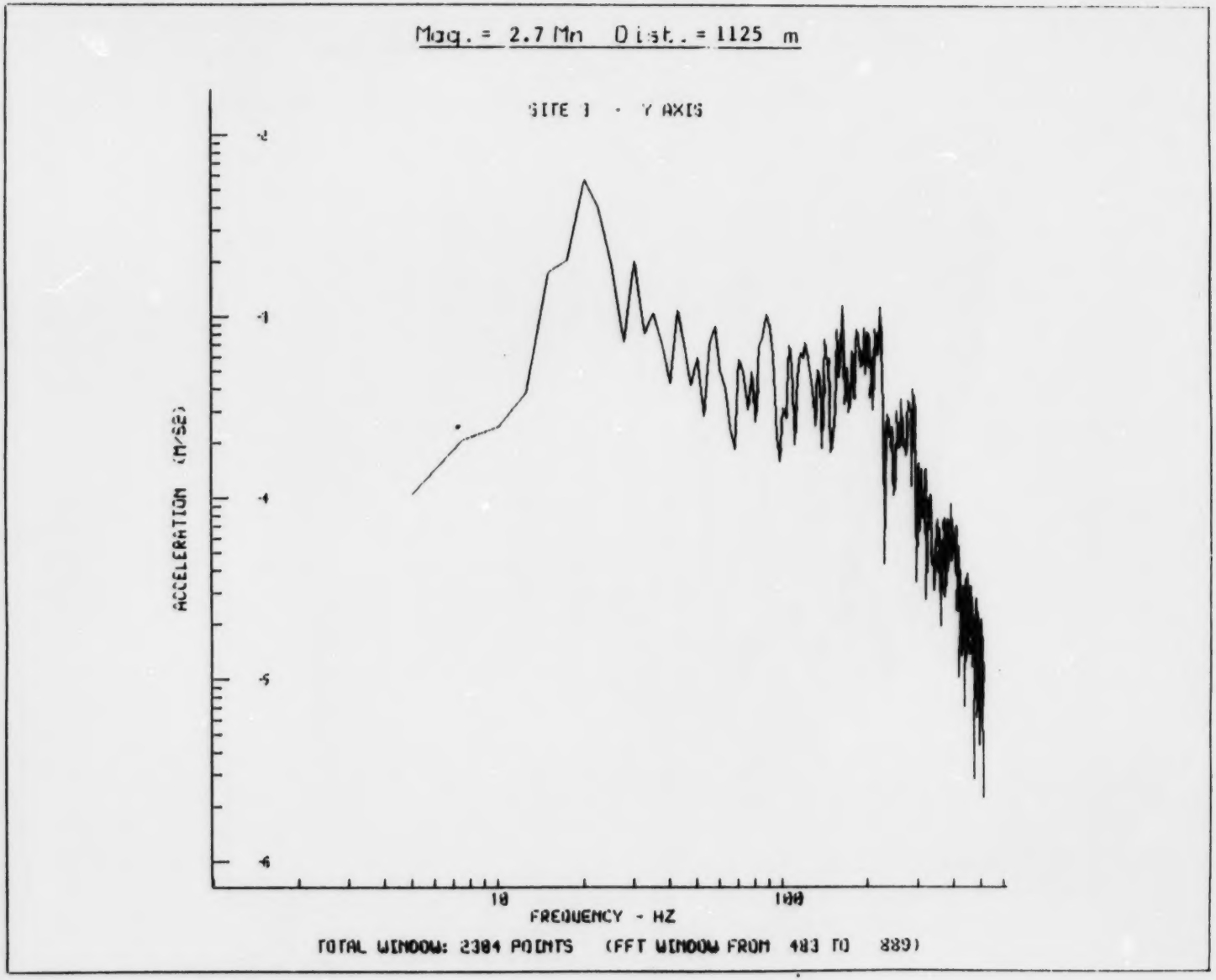

Fig. 4.18.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

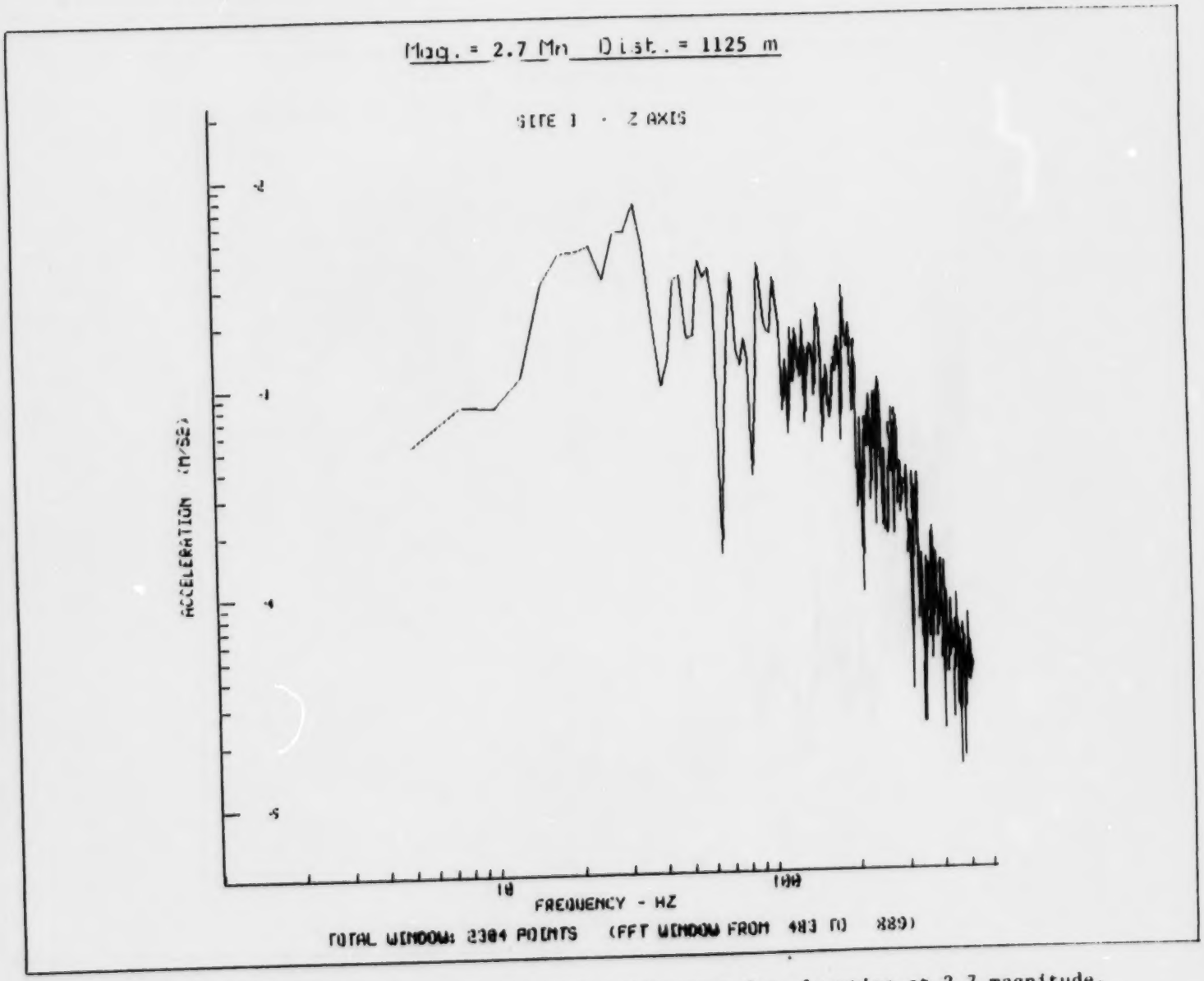

Fig. 4.18.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

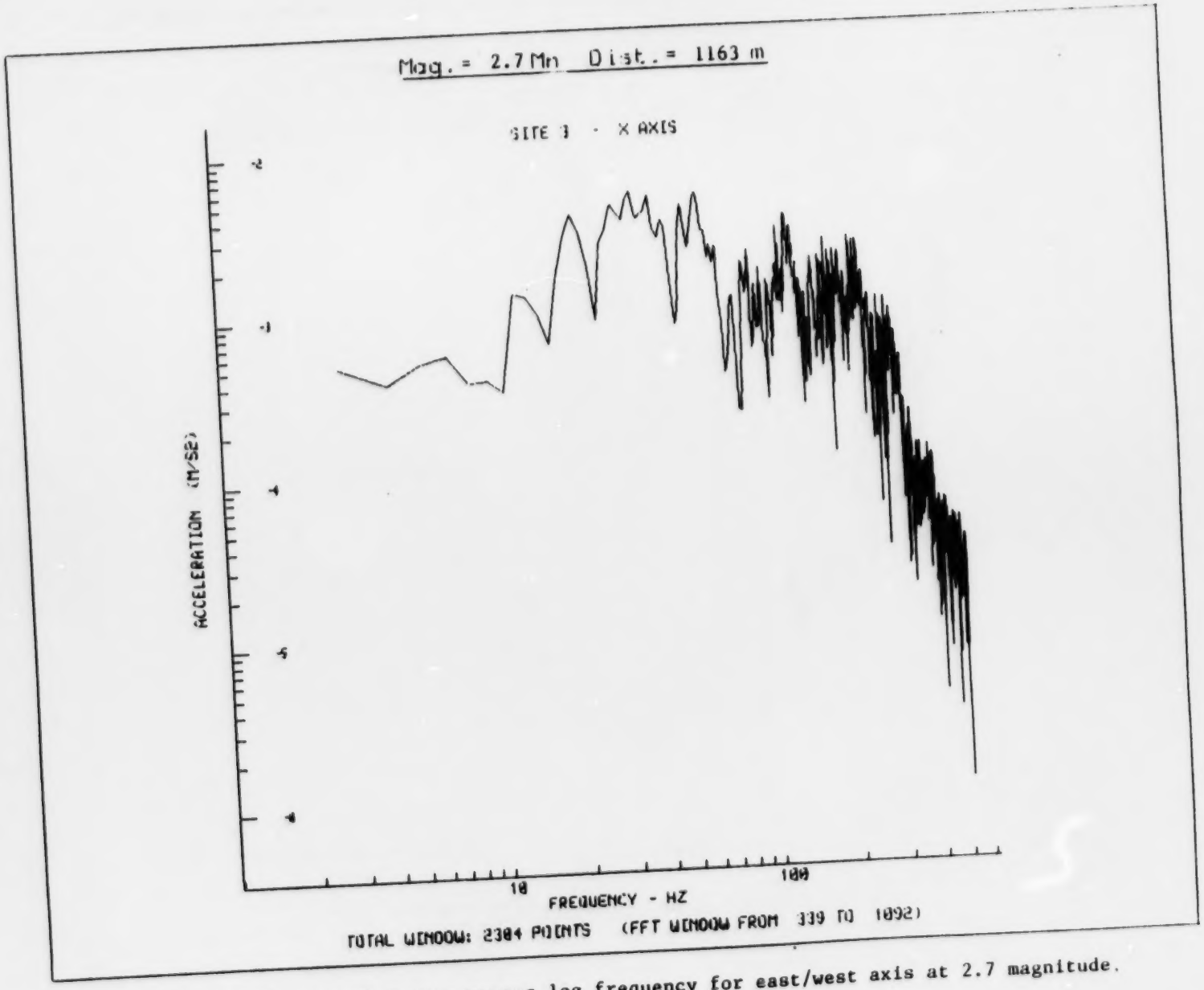

Fig. 4.19.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

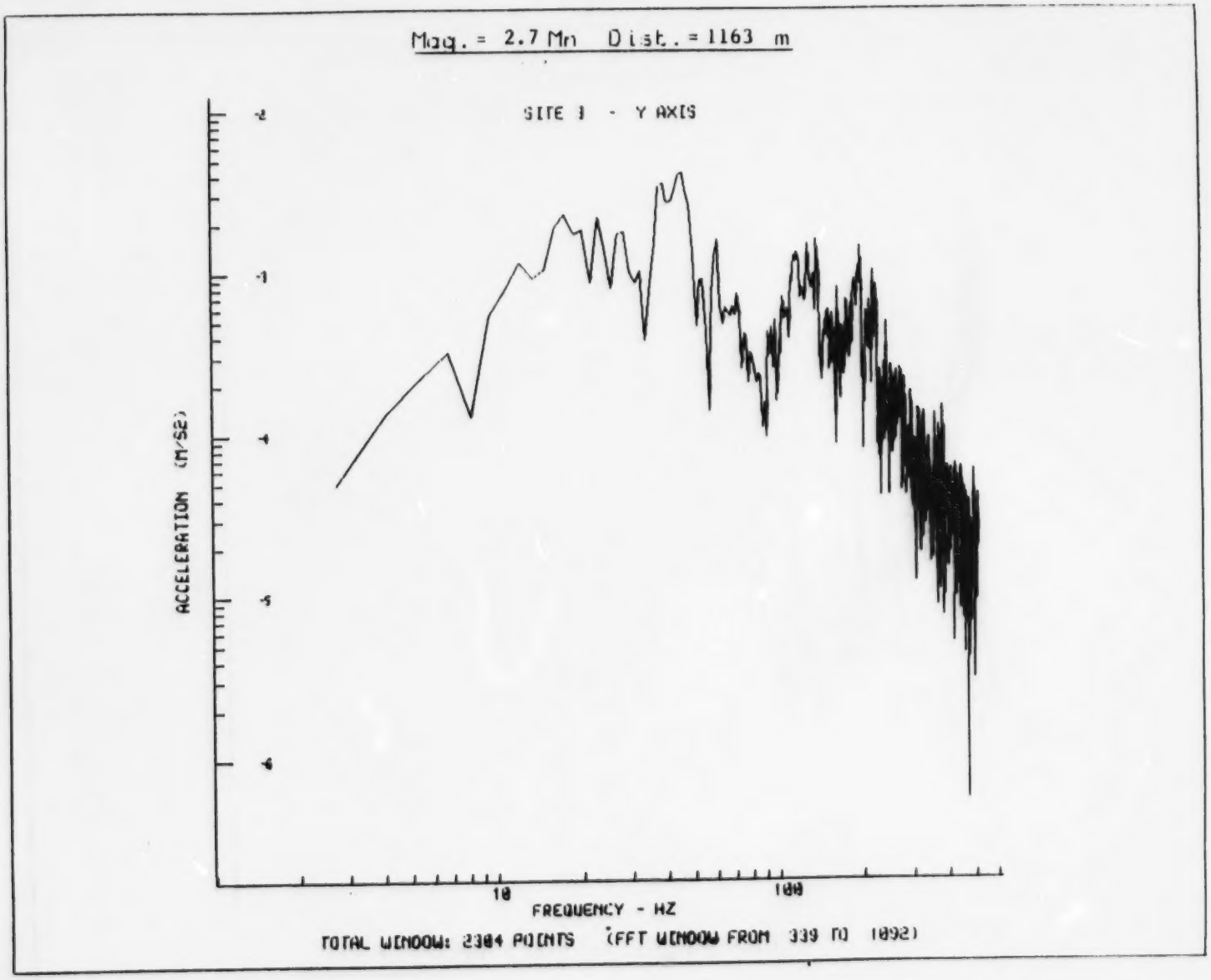

Fig. 4.19.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

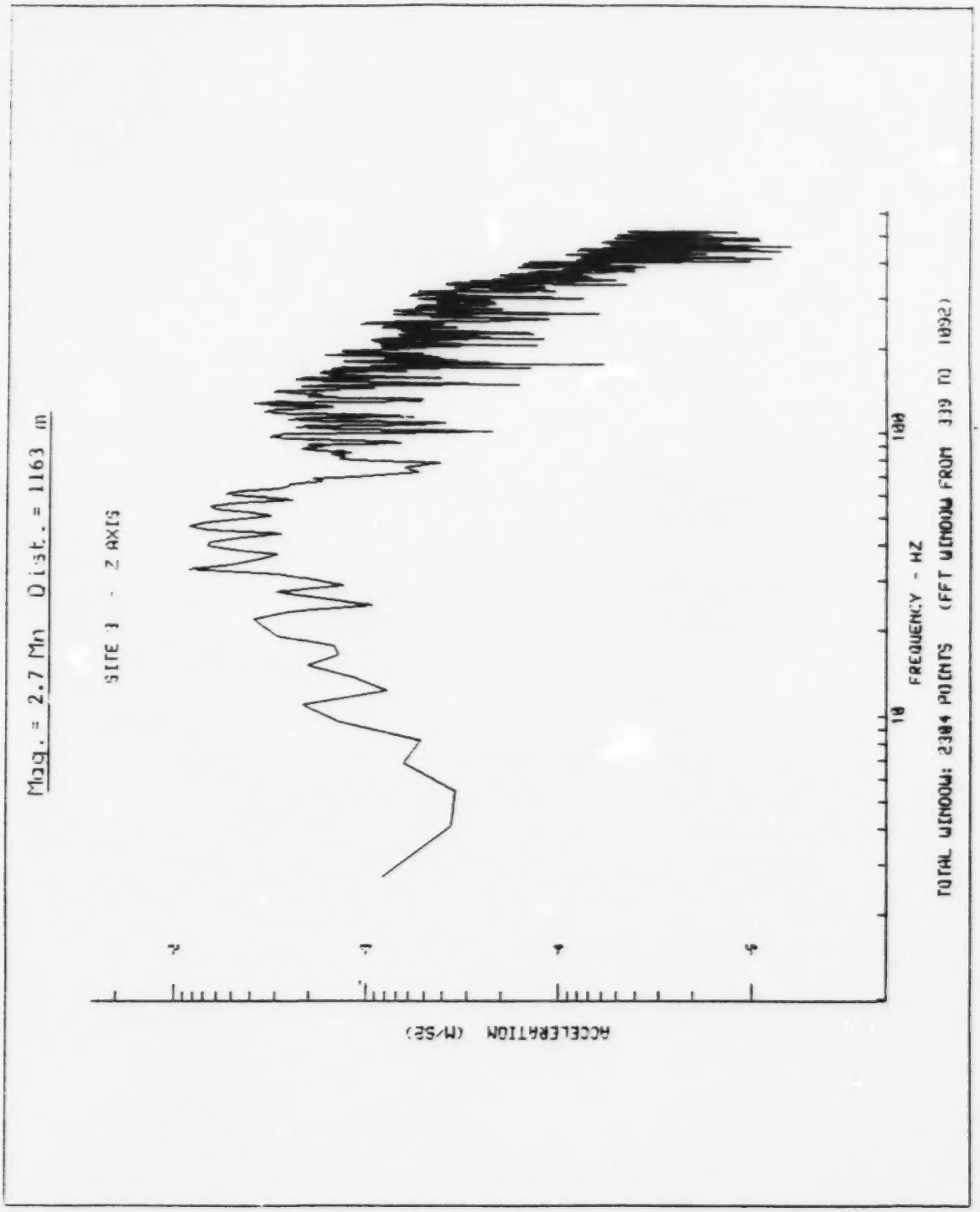

Fig. 4.19.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude

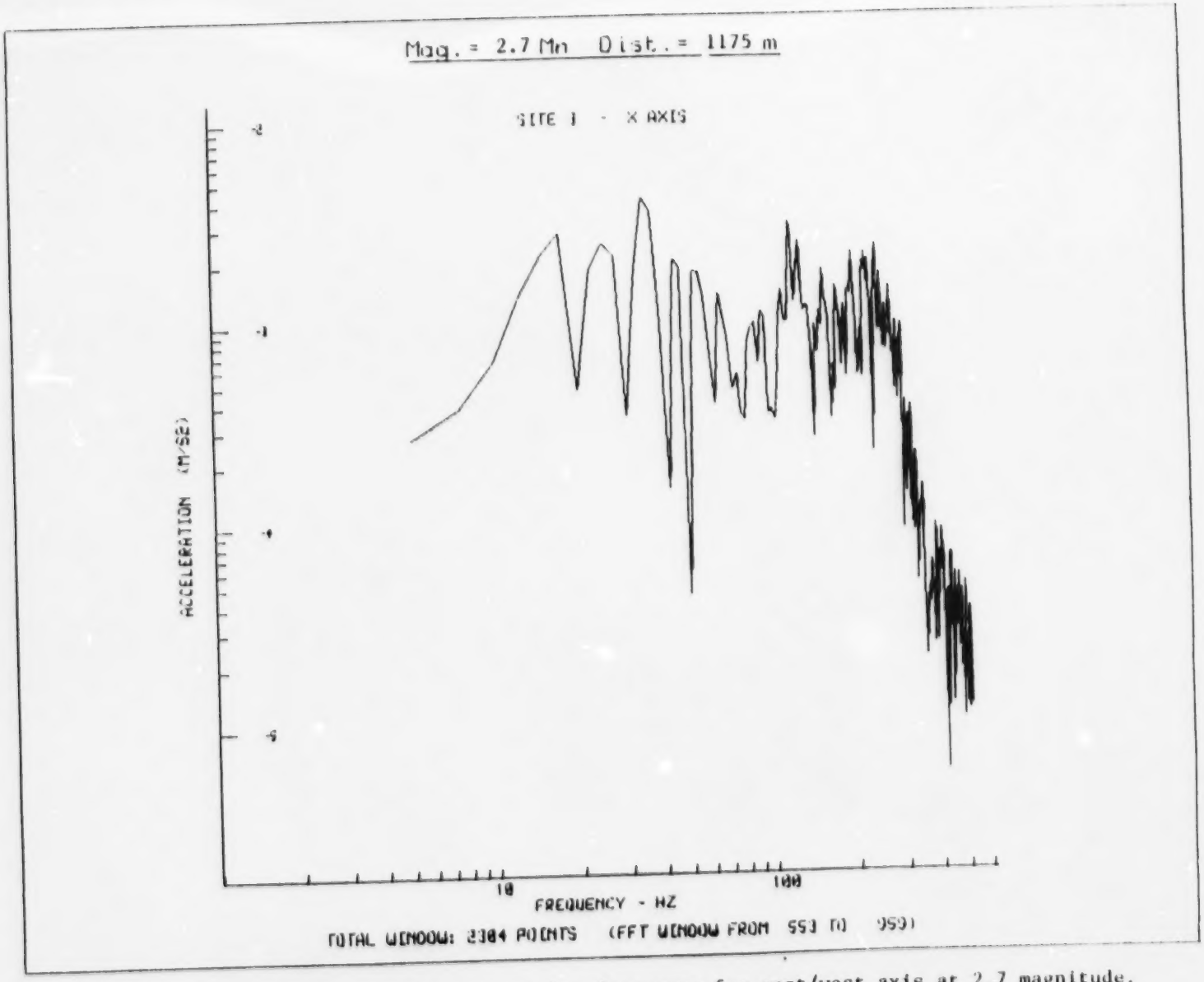

Fig. 4.20.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

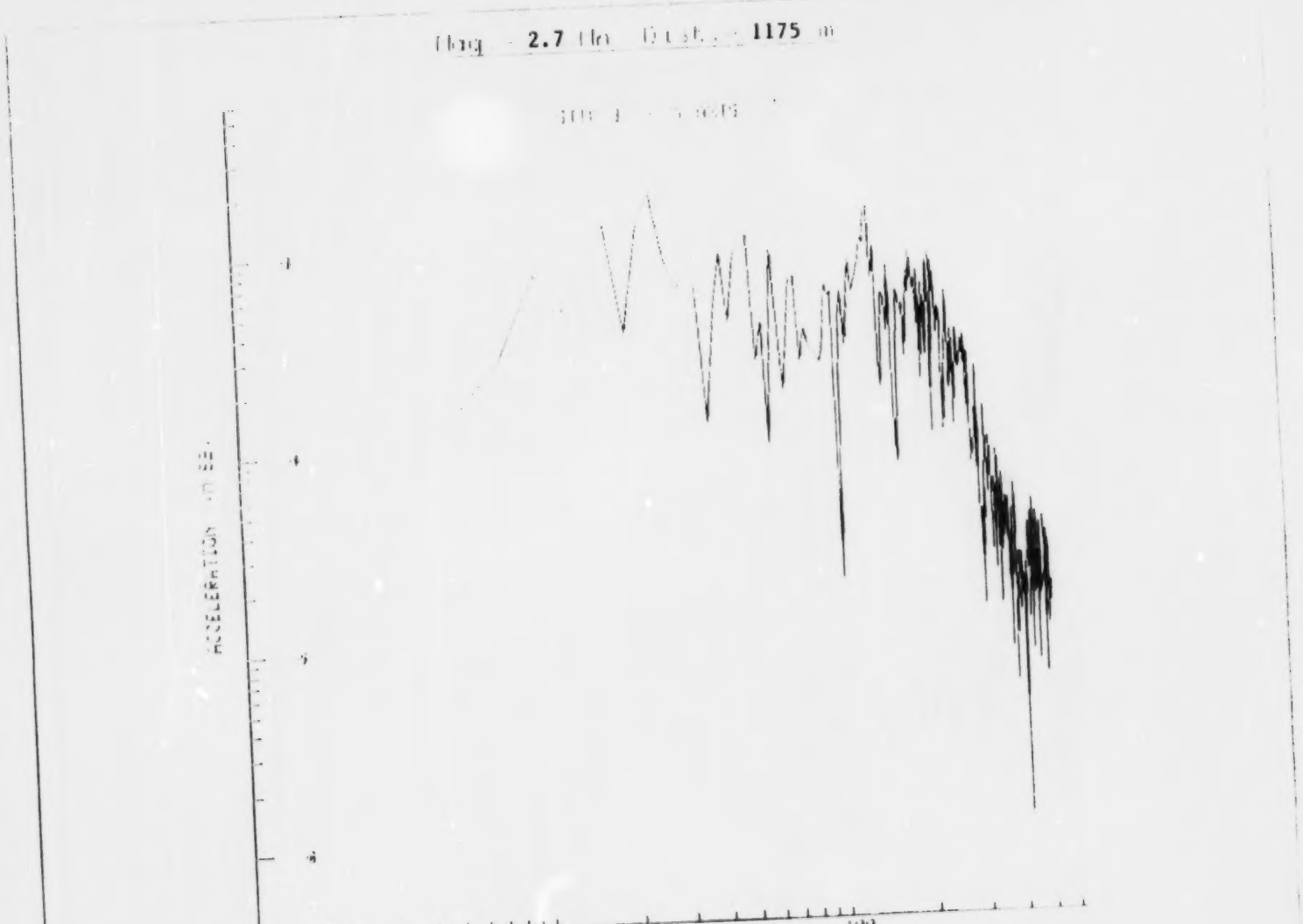

Fig. 4.20.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

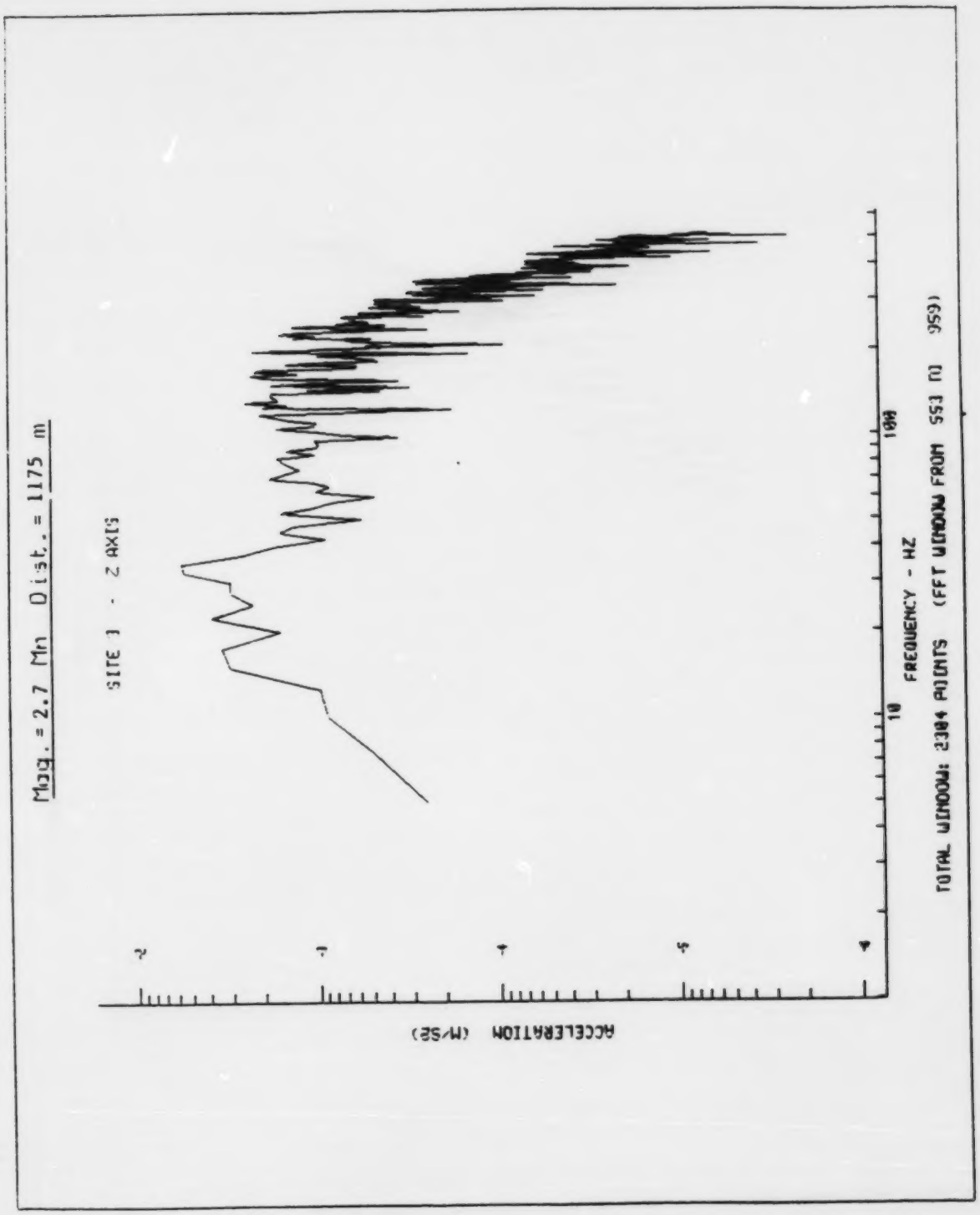

Fig. 4.20.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

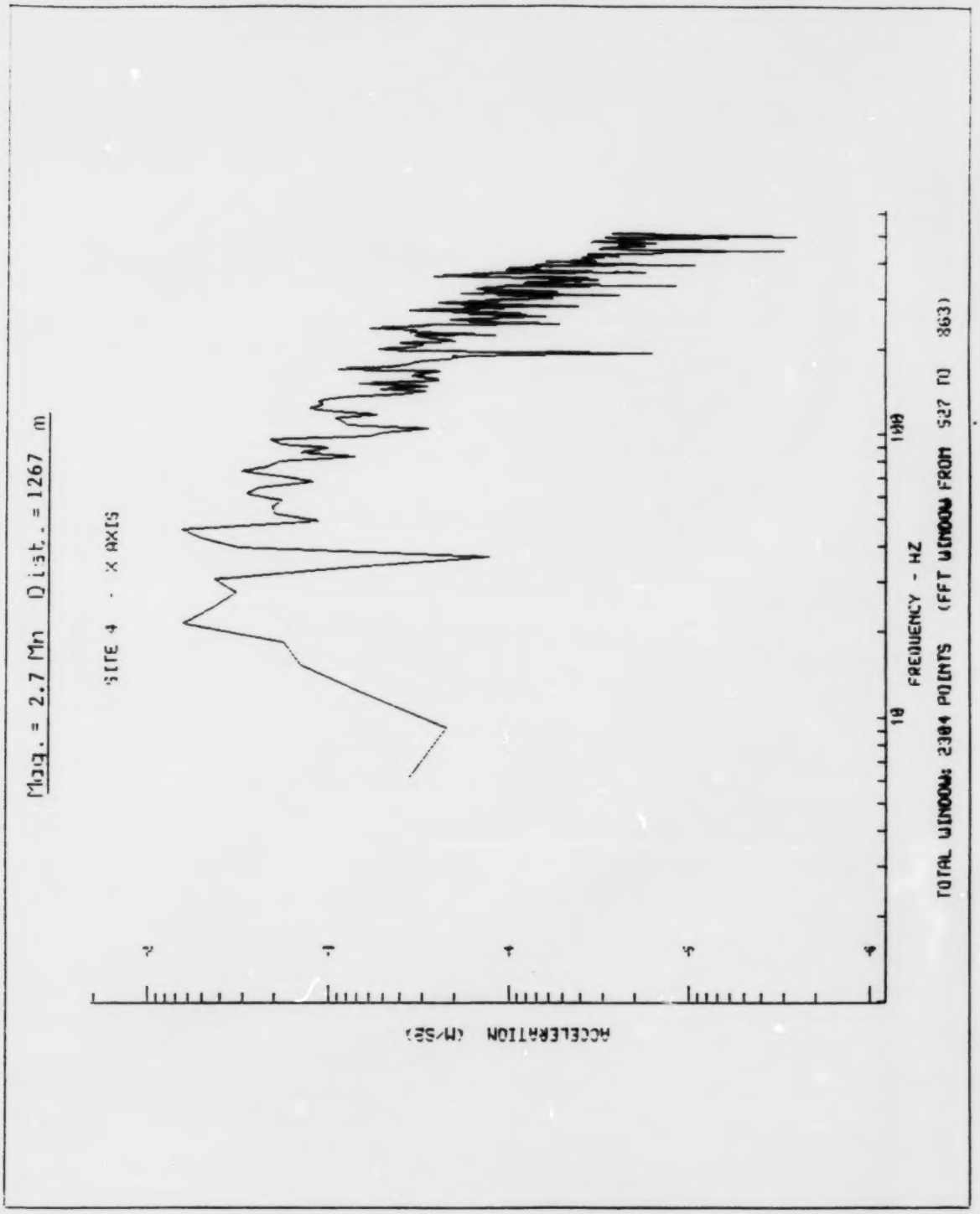

Fig. 4.21.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

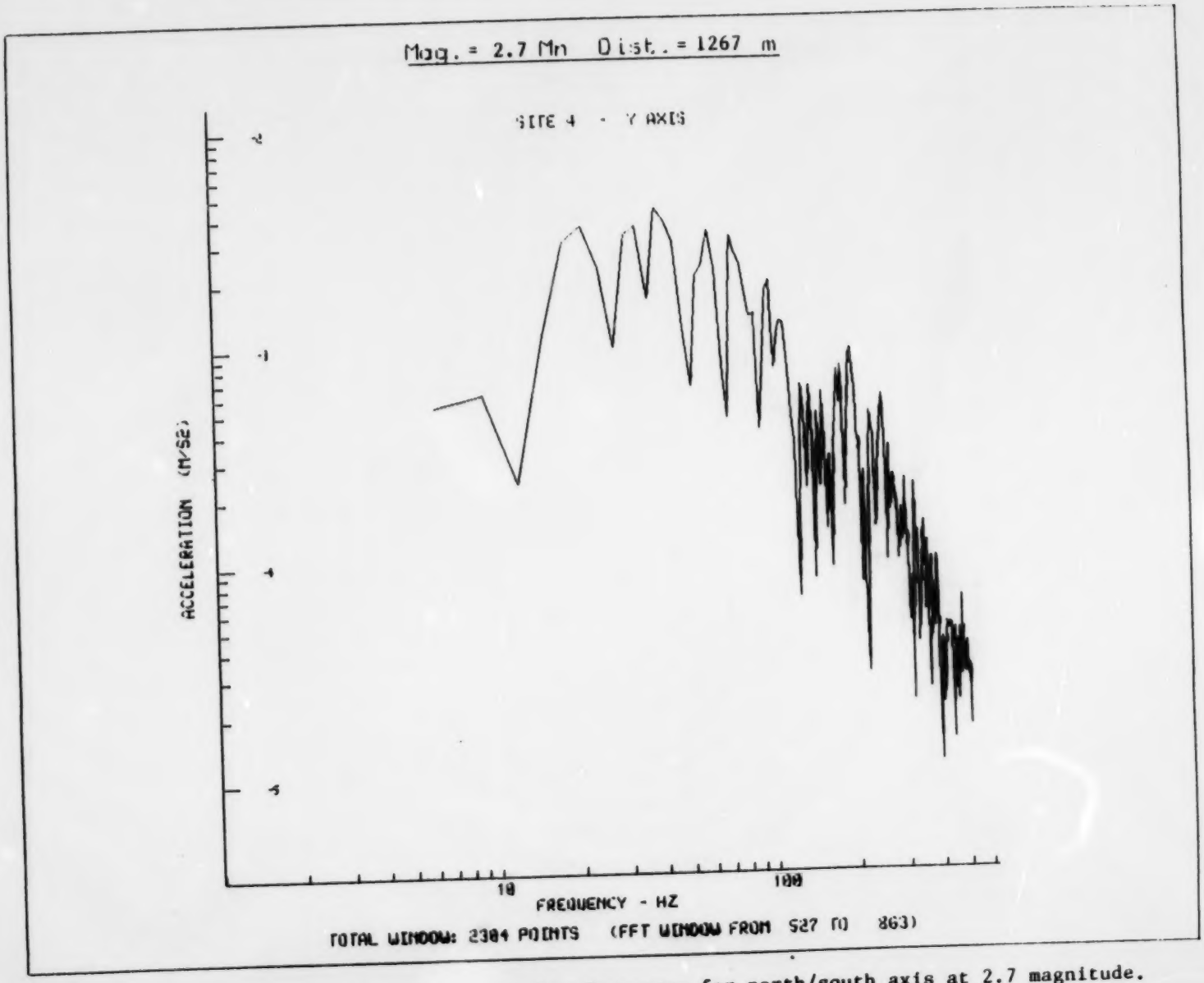

Fig. 4.21.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

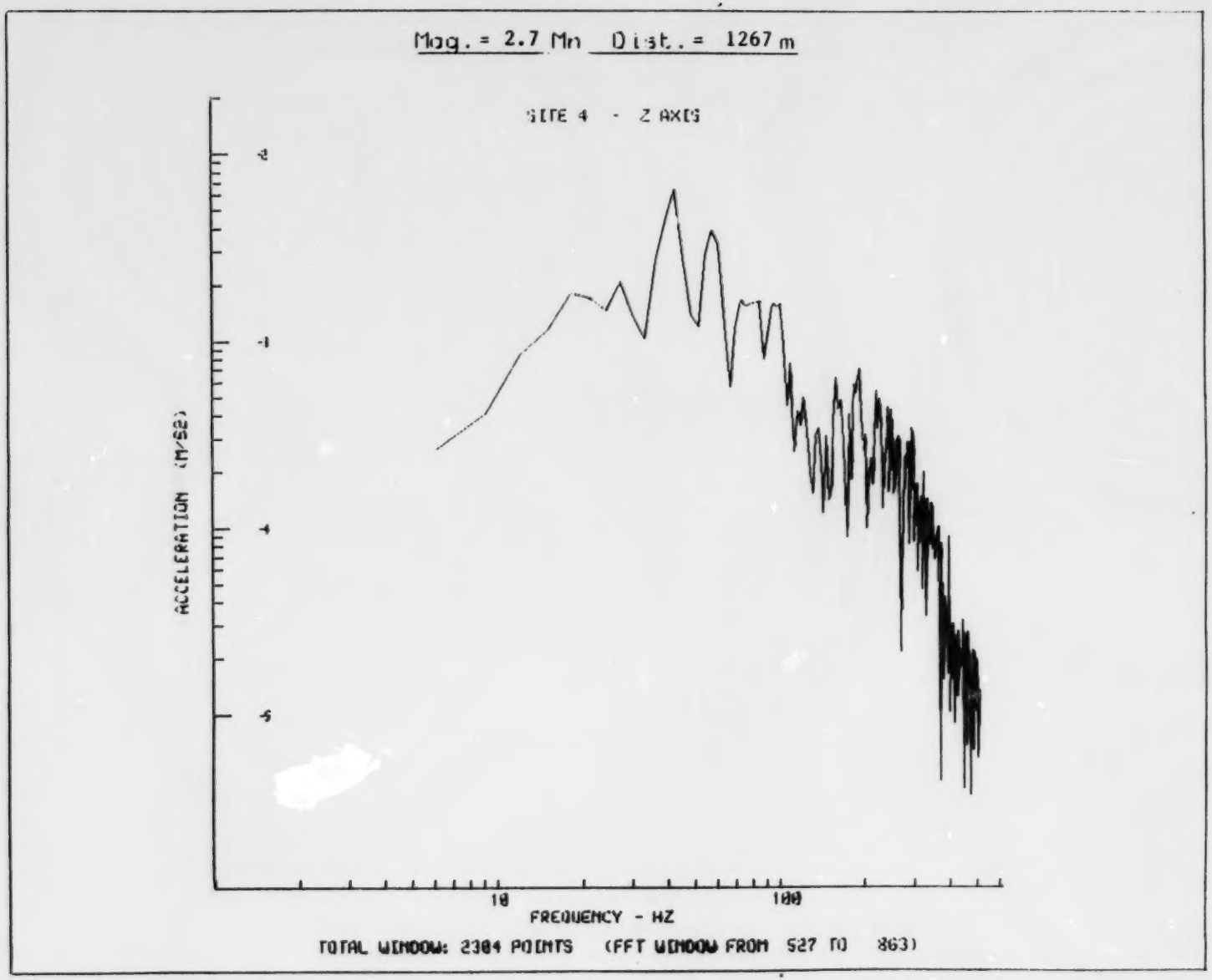

Fig. 4.21.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

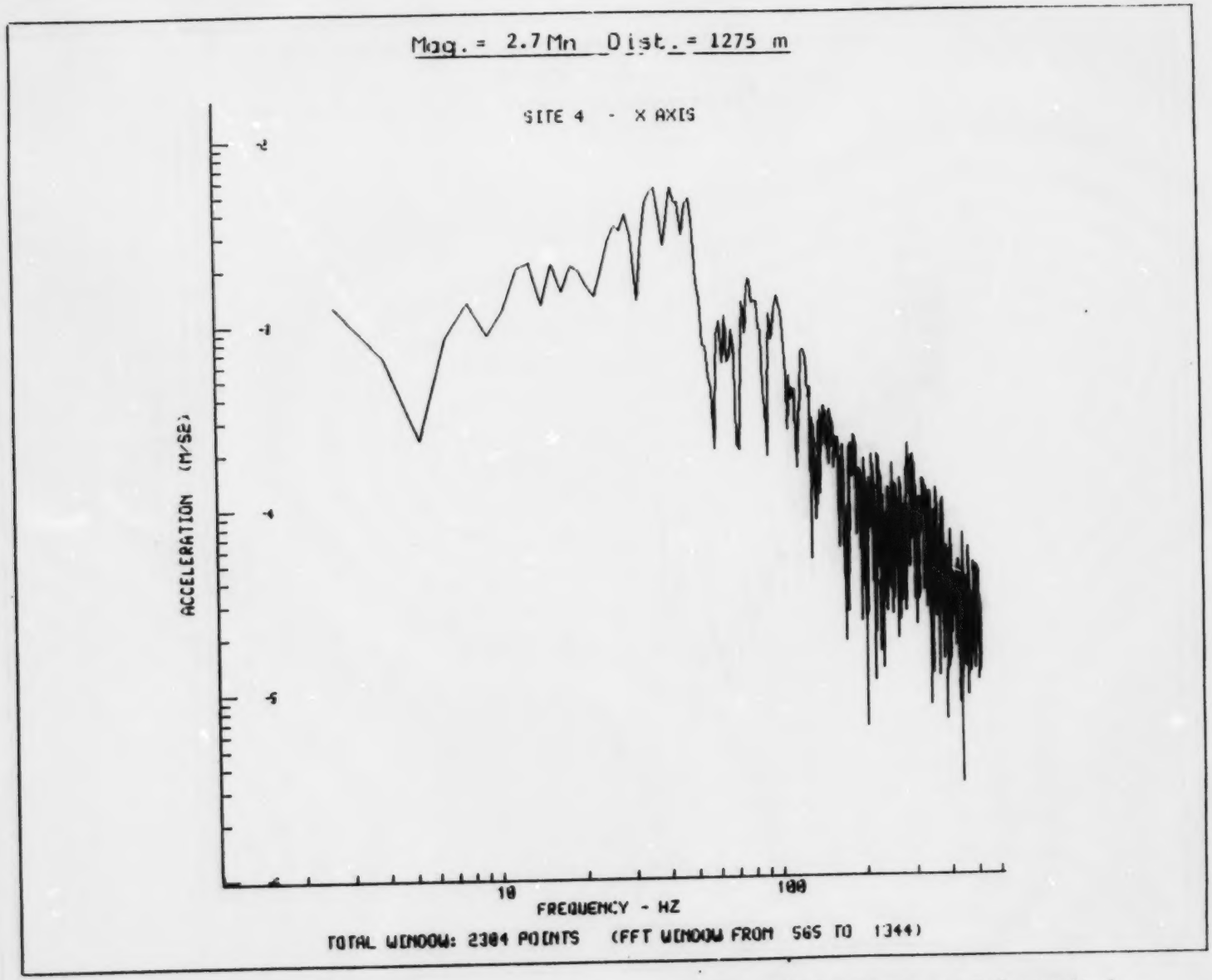

Fig. 4.22.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

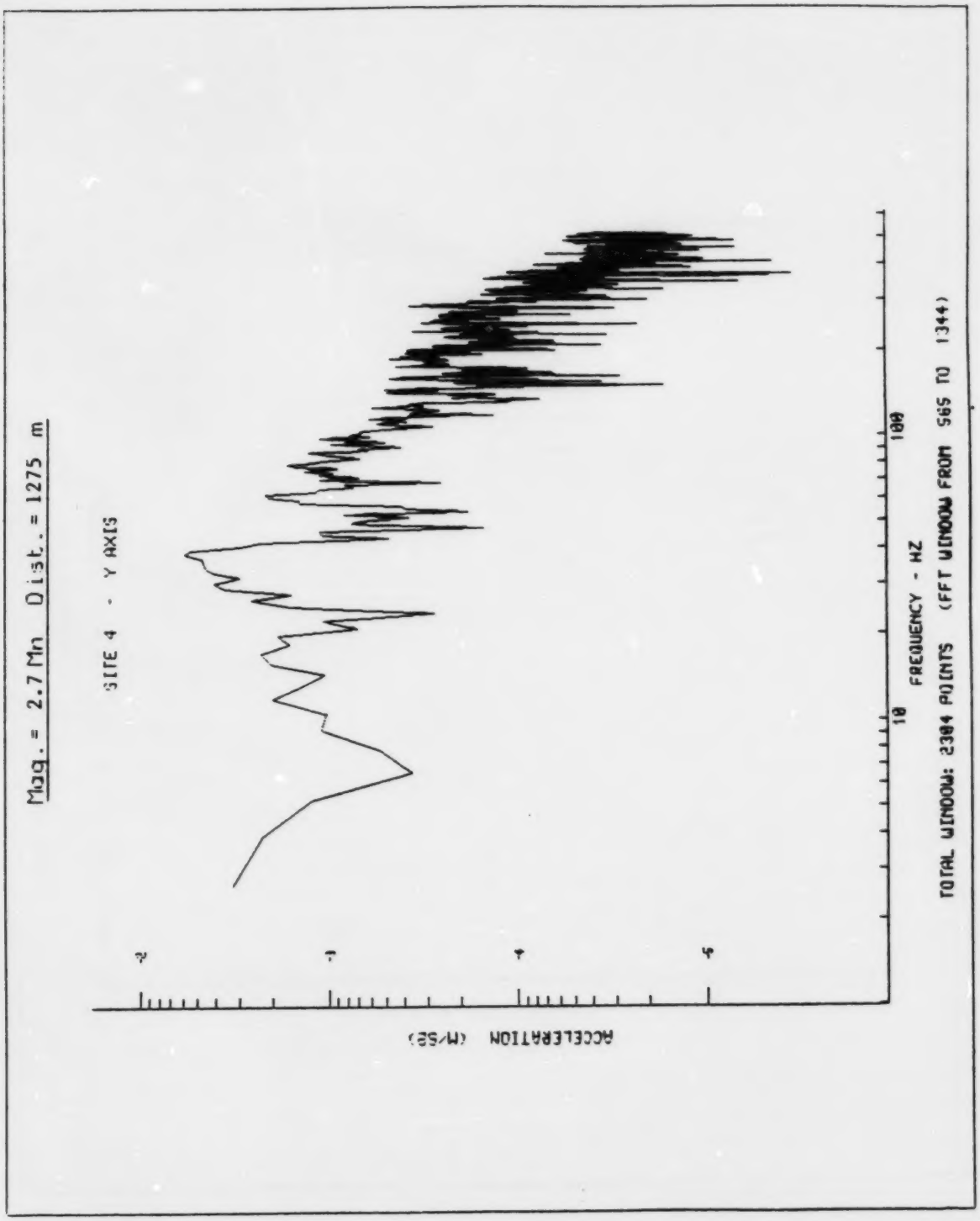

Fig. 4.22.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

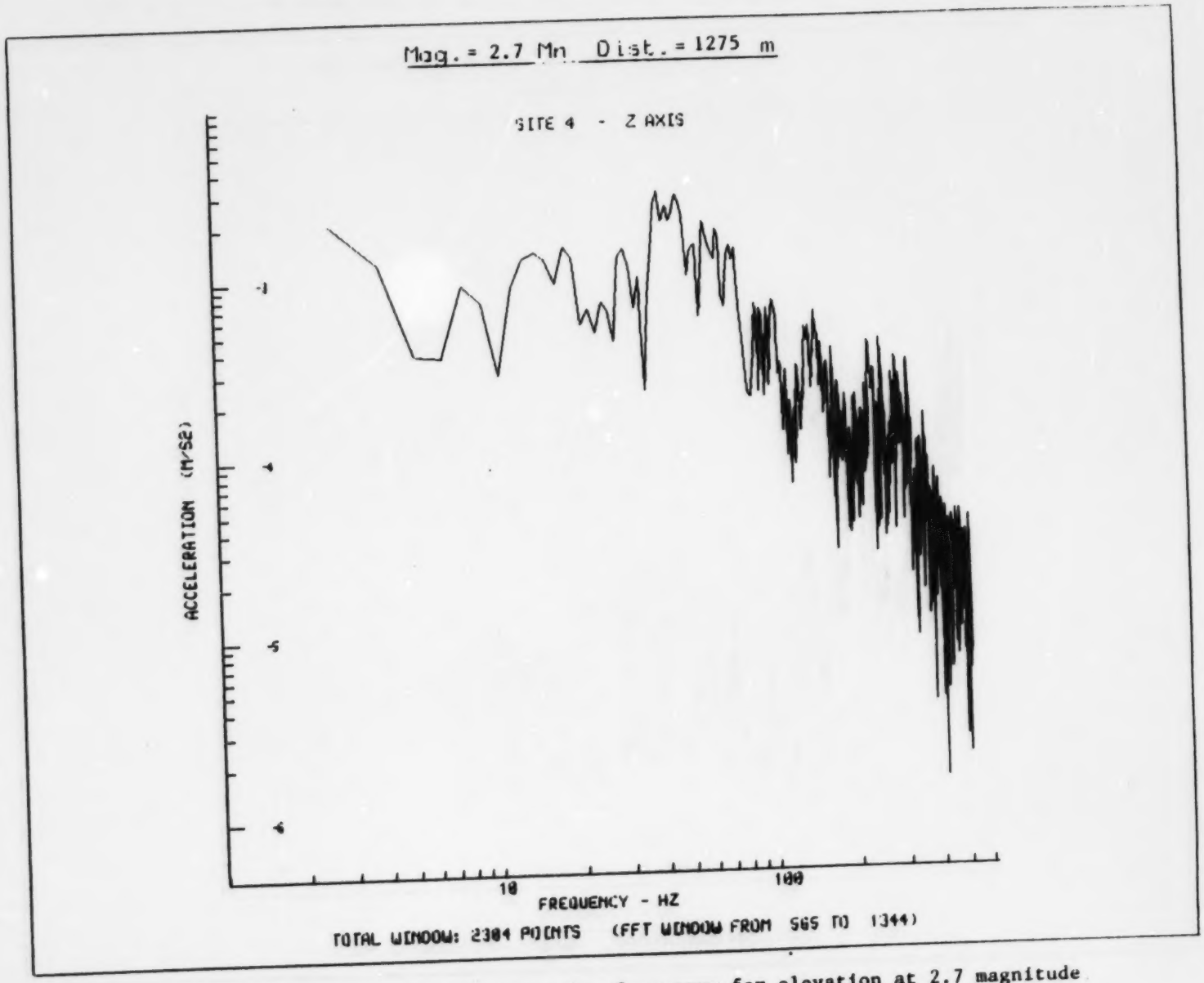

Fig. 4.22.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude

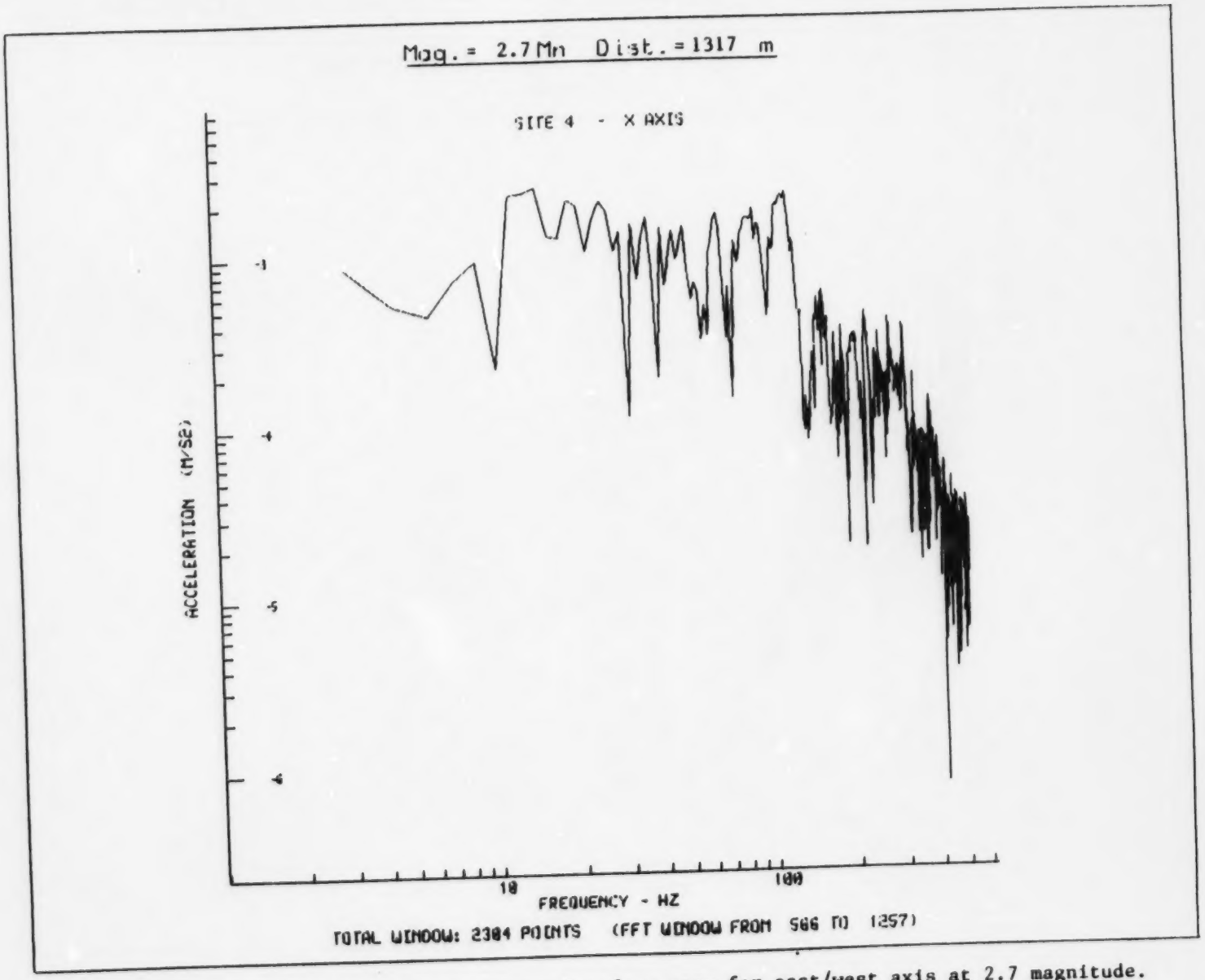

Fig. 4.23.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

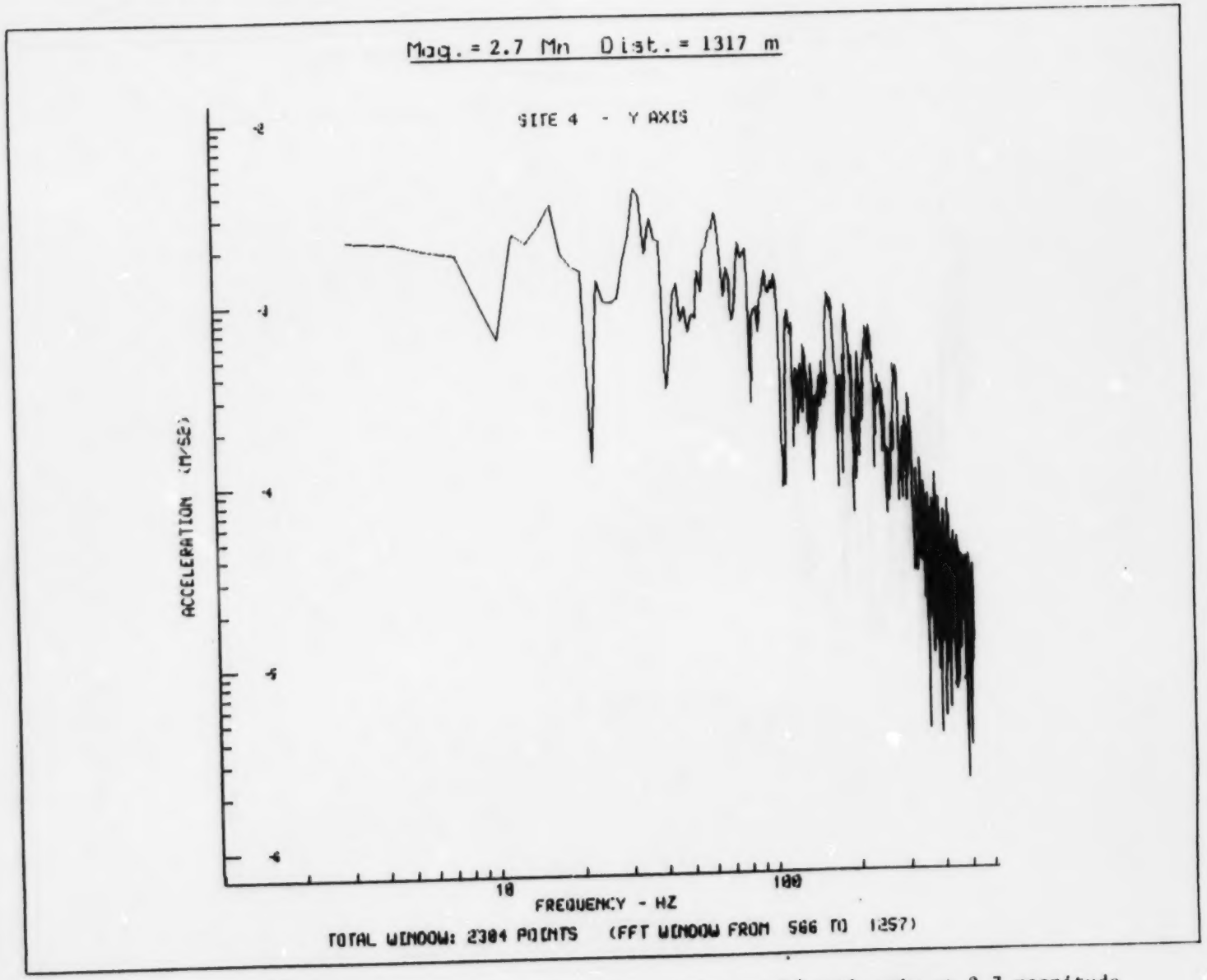
Mag. = 2.7 Mn Dist. = 1317 m
SITE 4 - Y AXIS
ACCELERATION (M/SE)
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2304 POINTS (FFT WINDOW FROM 566 TO 1257)

Fig. 4.23.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude

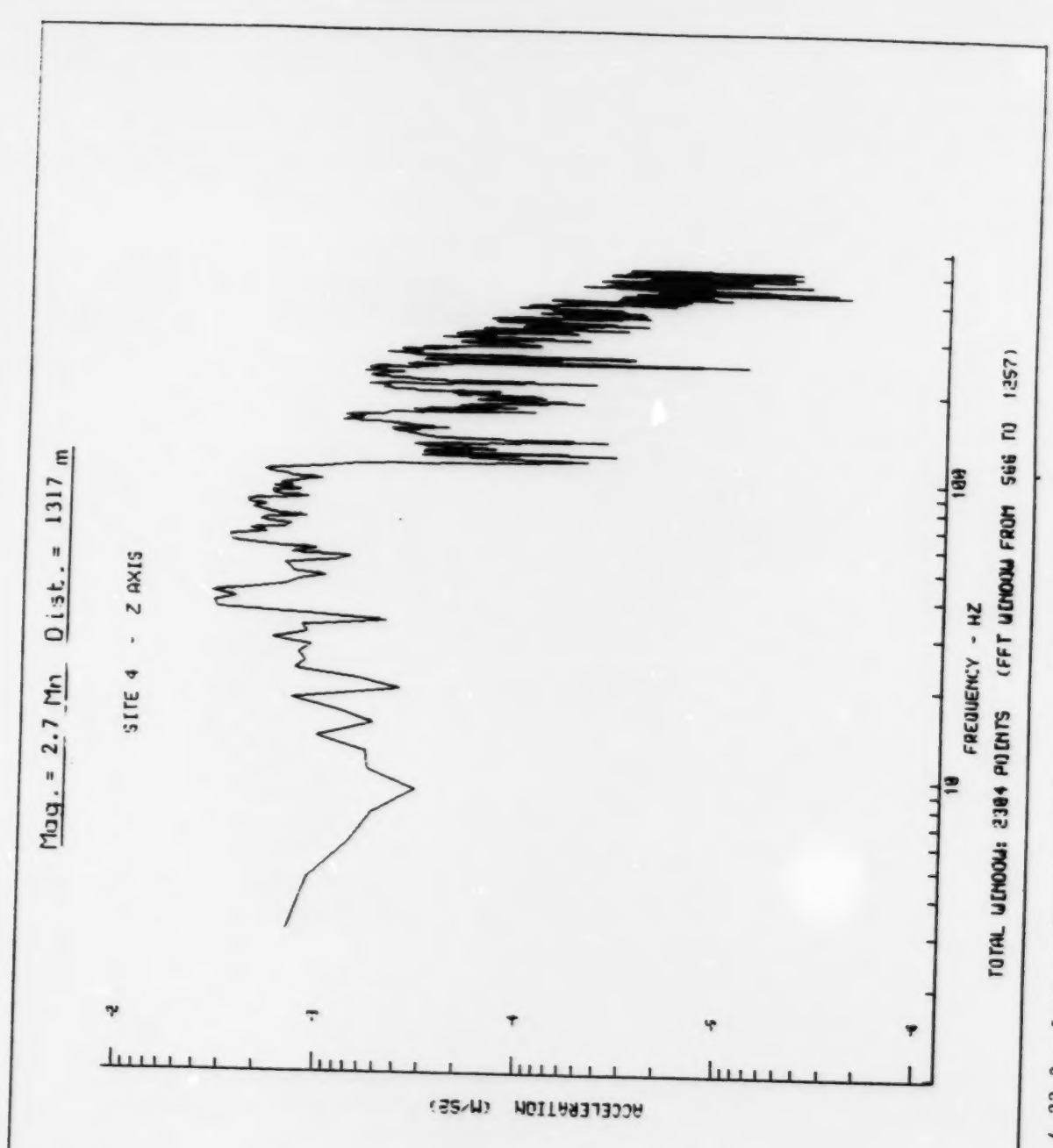

Fig. 4.23.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

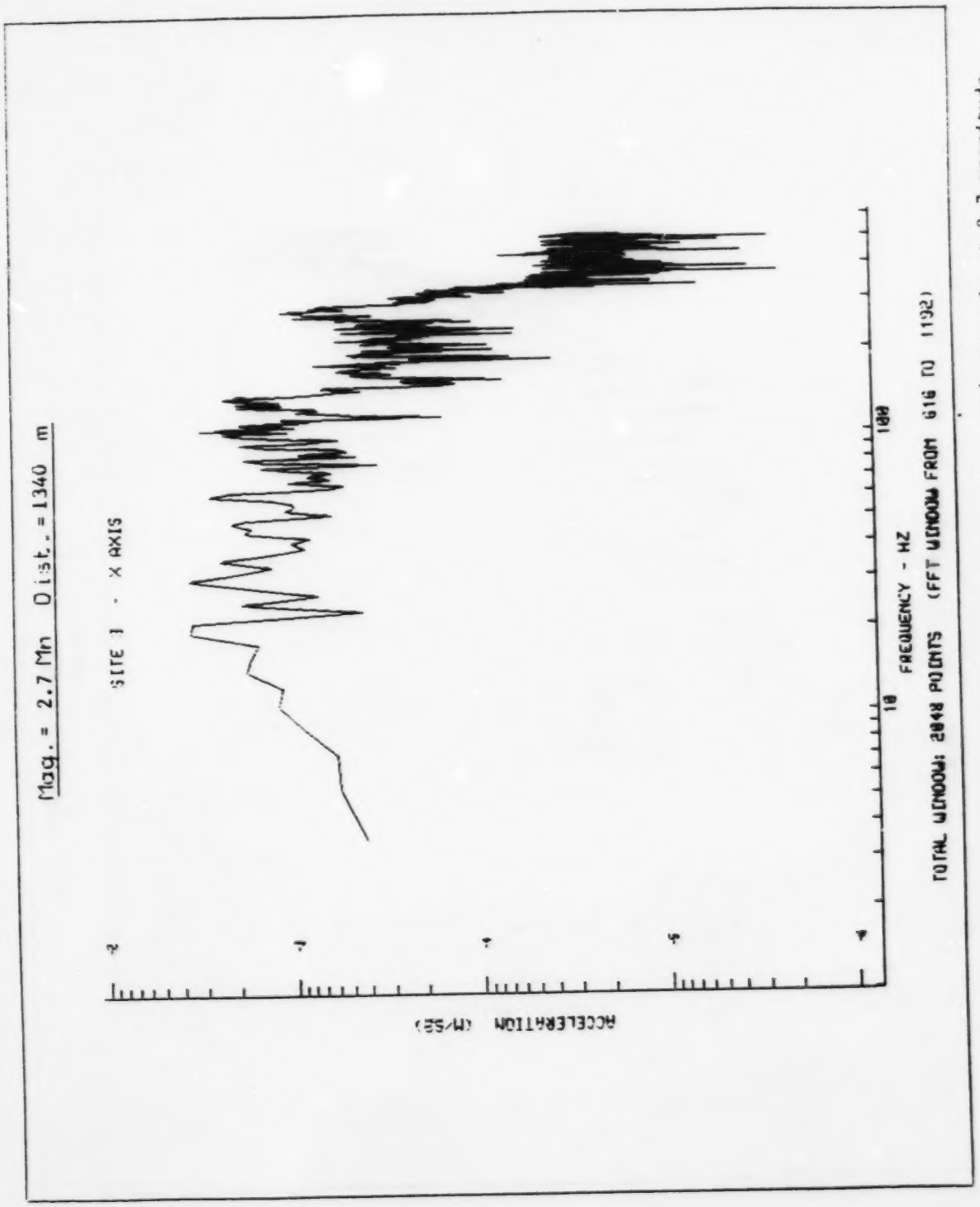

Fig. 4.24.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

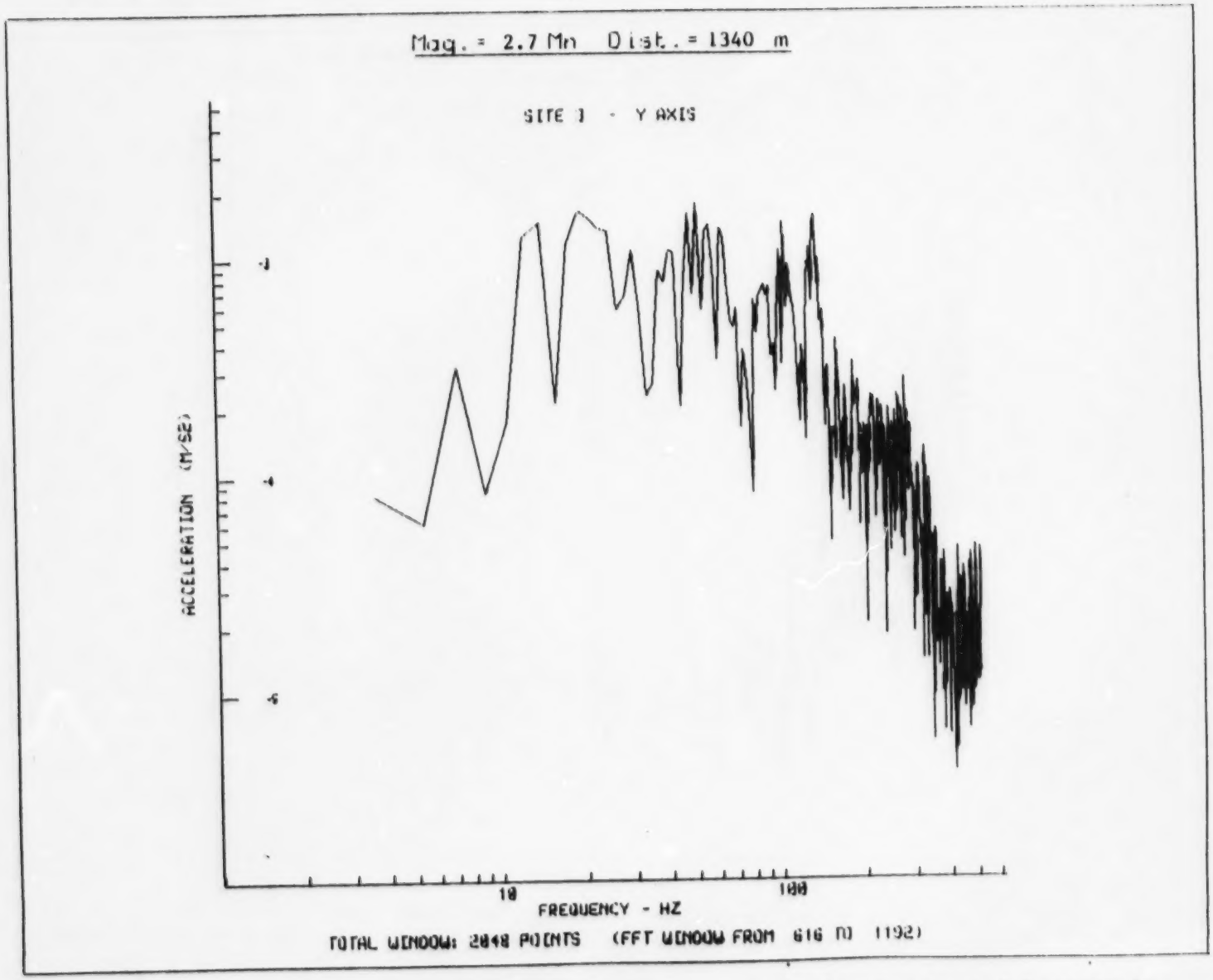
Mag. = 2.7 Mn Dist. = 1340 m
SITE 1 - Y AXIS
ACCELERATION (M/SE
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2048 POINTS (FFT WINDOW FROM 616 TO 1192)

Fig. 4.24.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

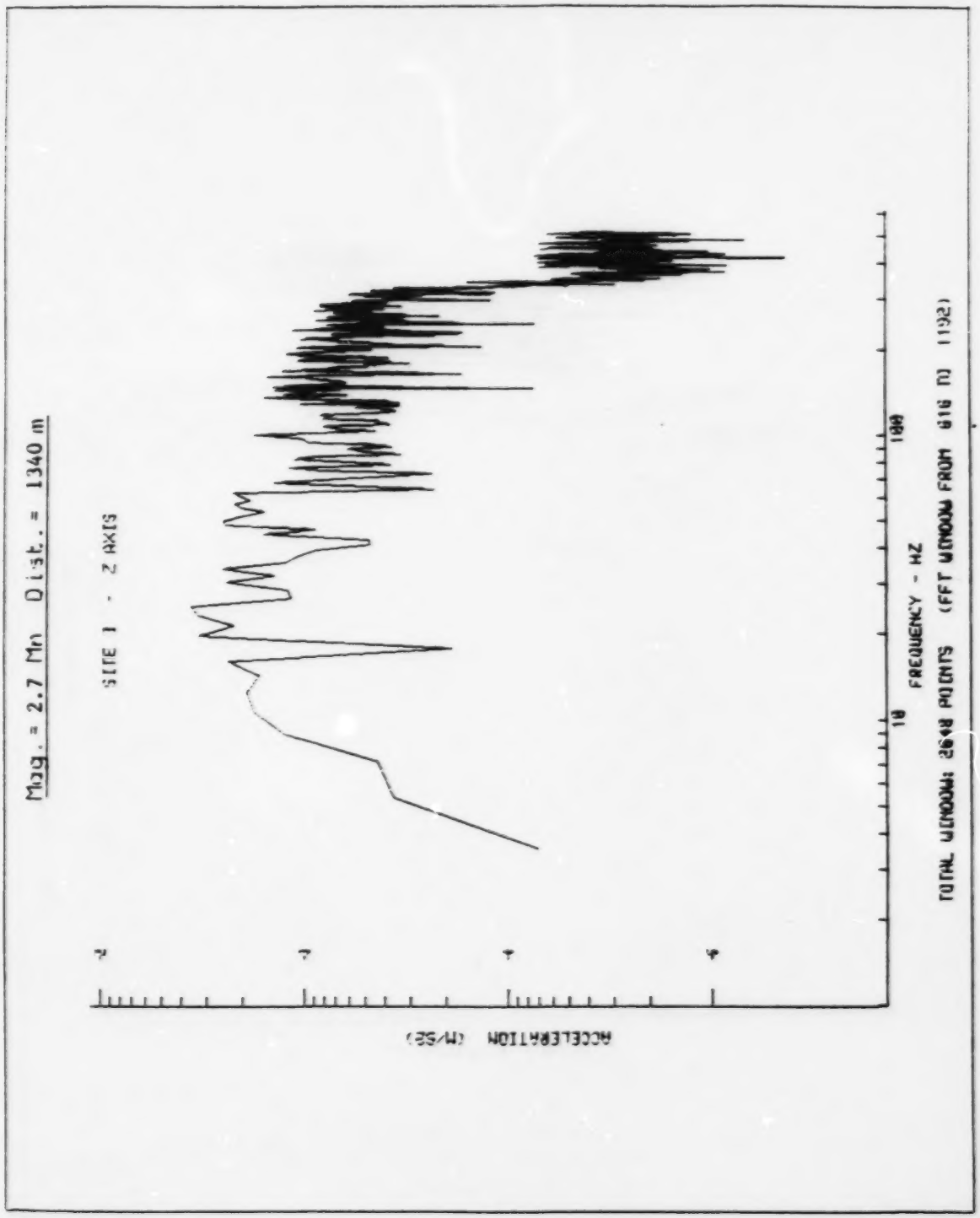

Fig. 4.24.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

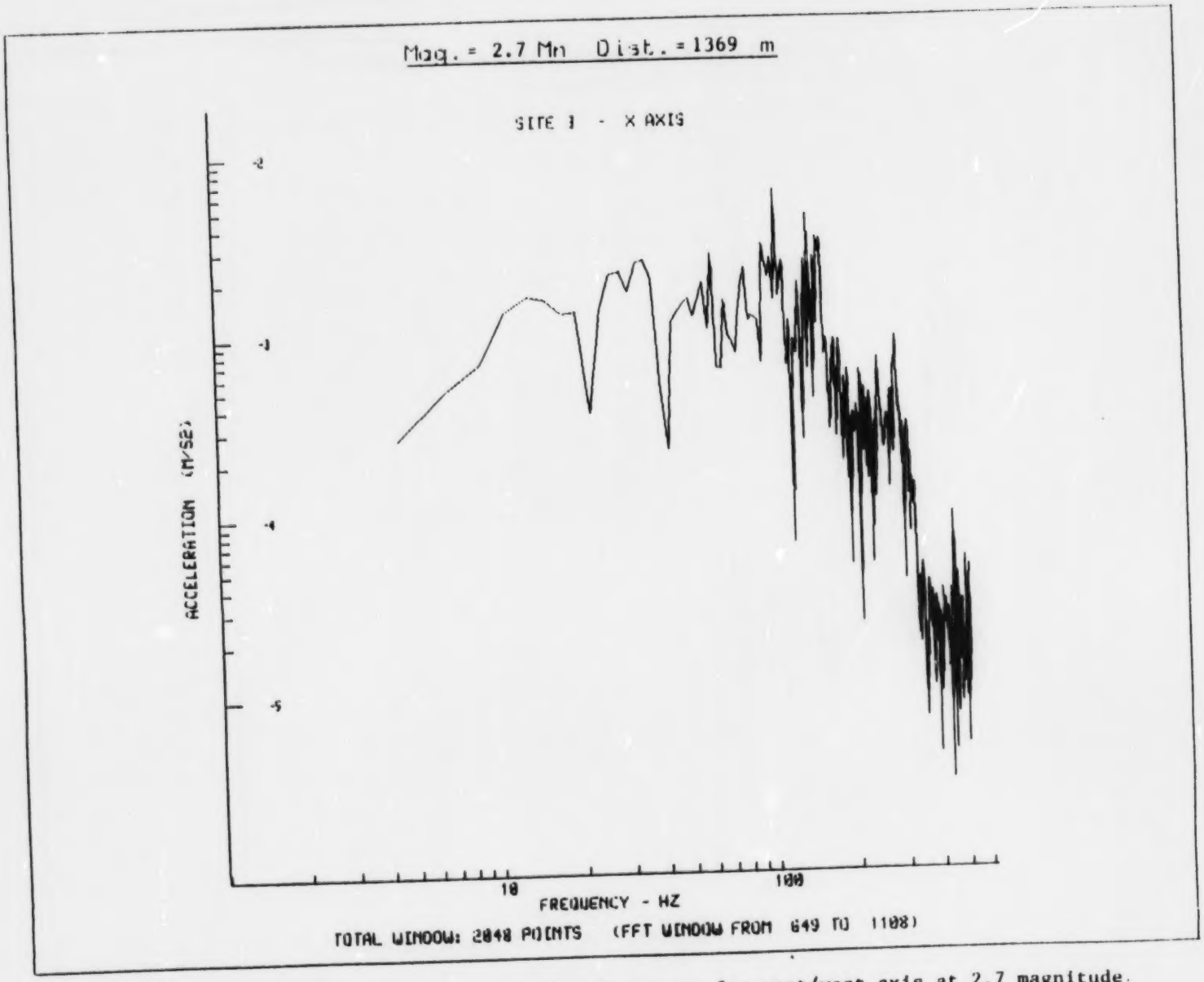

Fig. 4.25.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

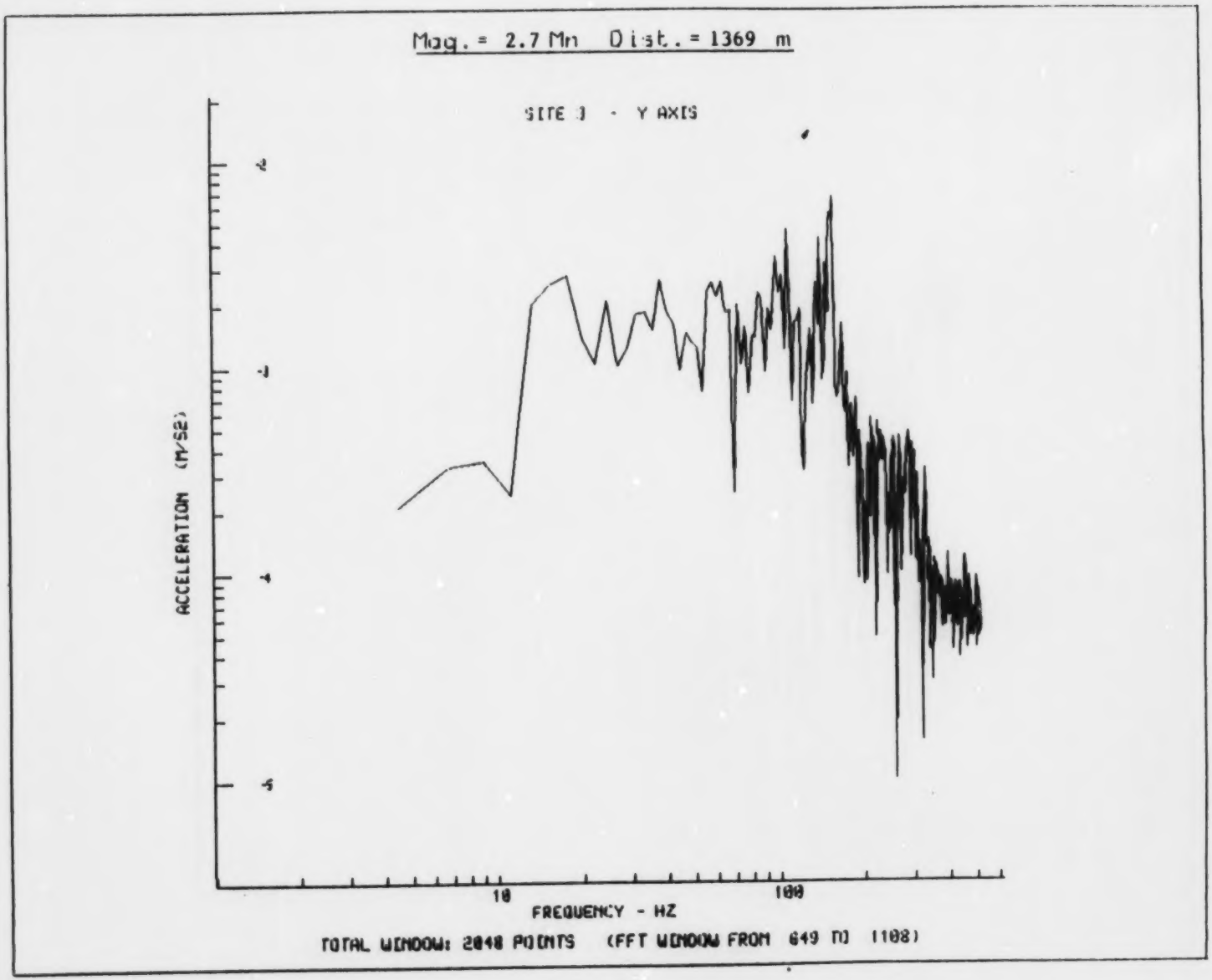

Fig. 4.25.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

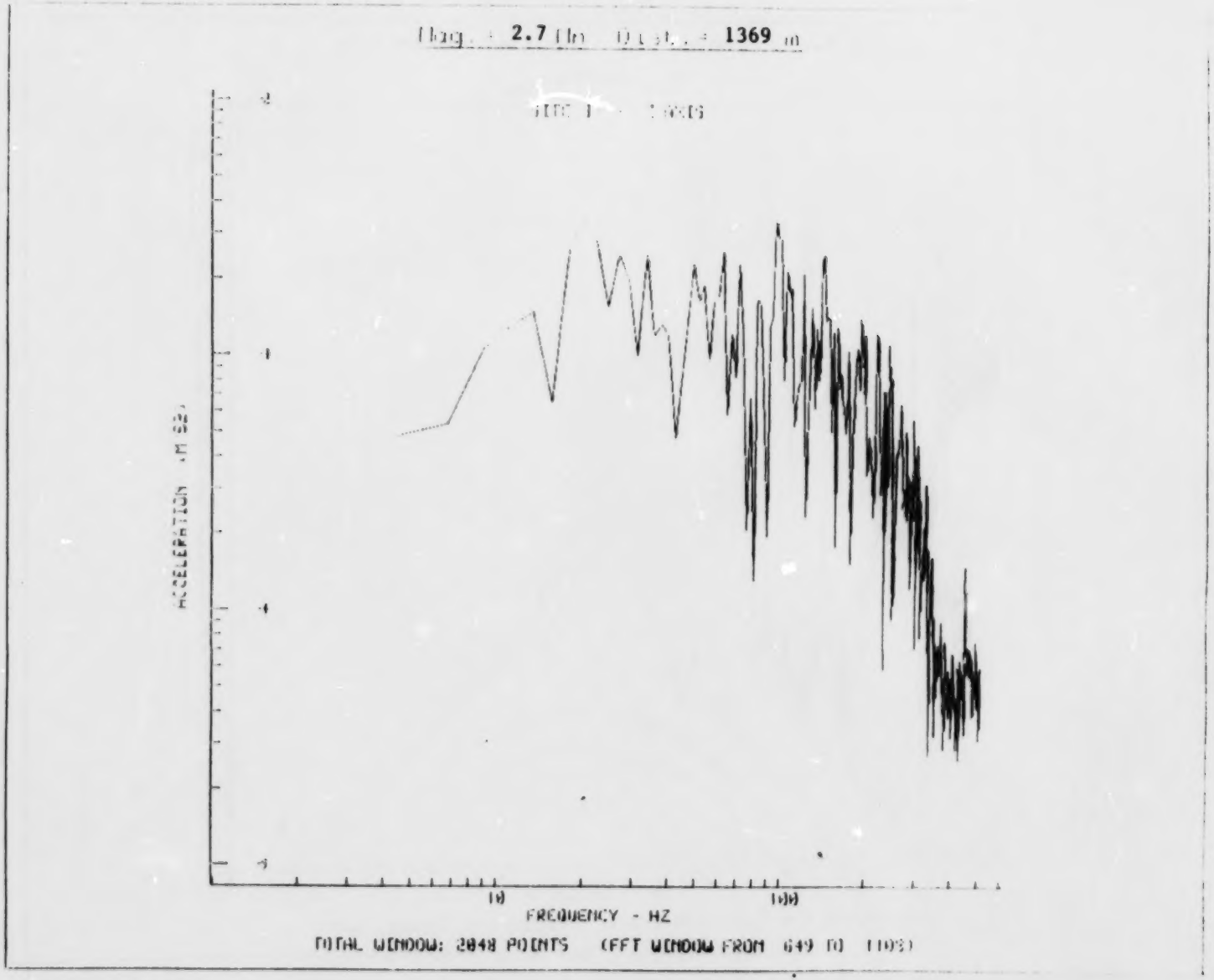

Fig. 4.25.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

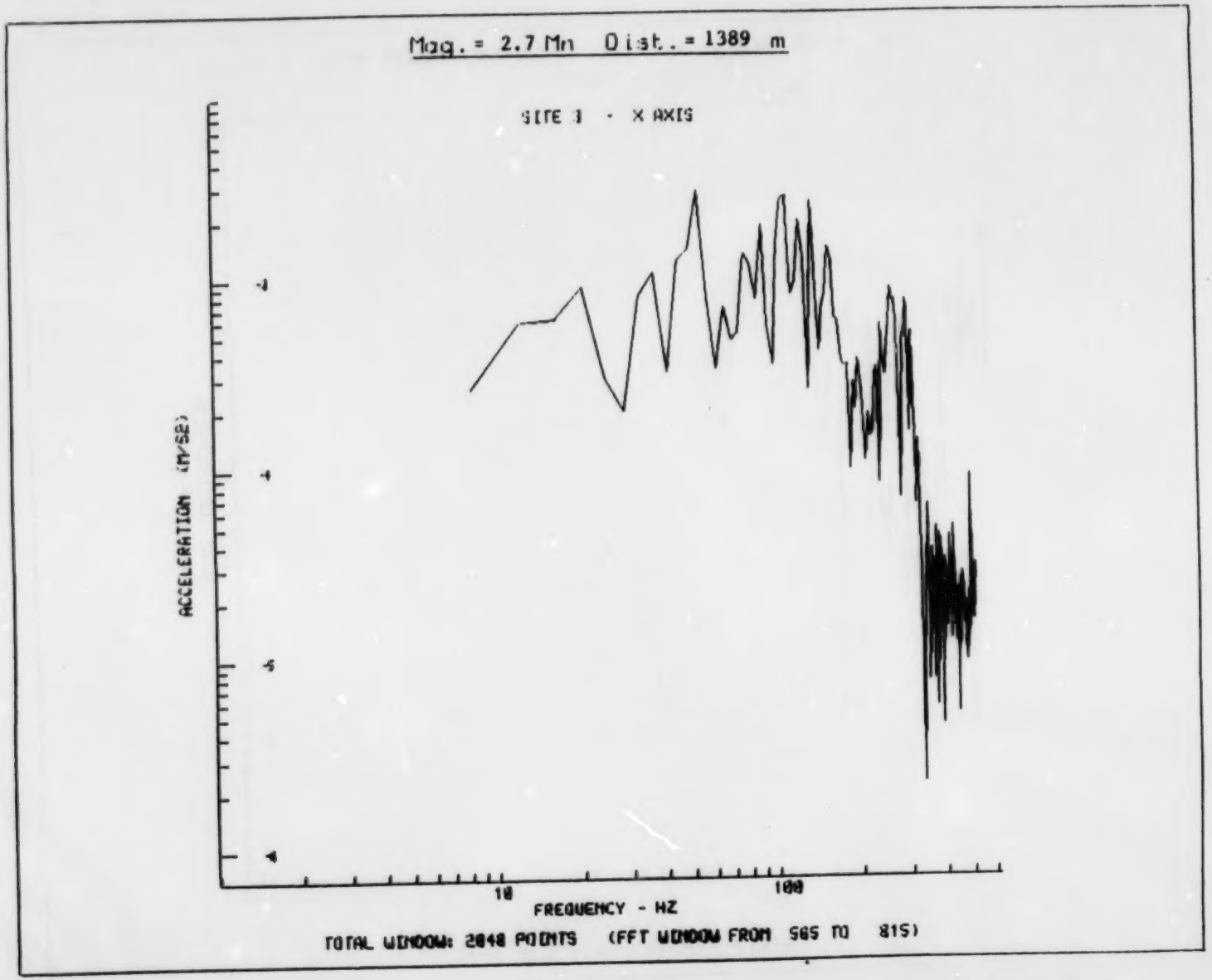

Fig. 4.26.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

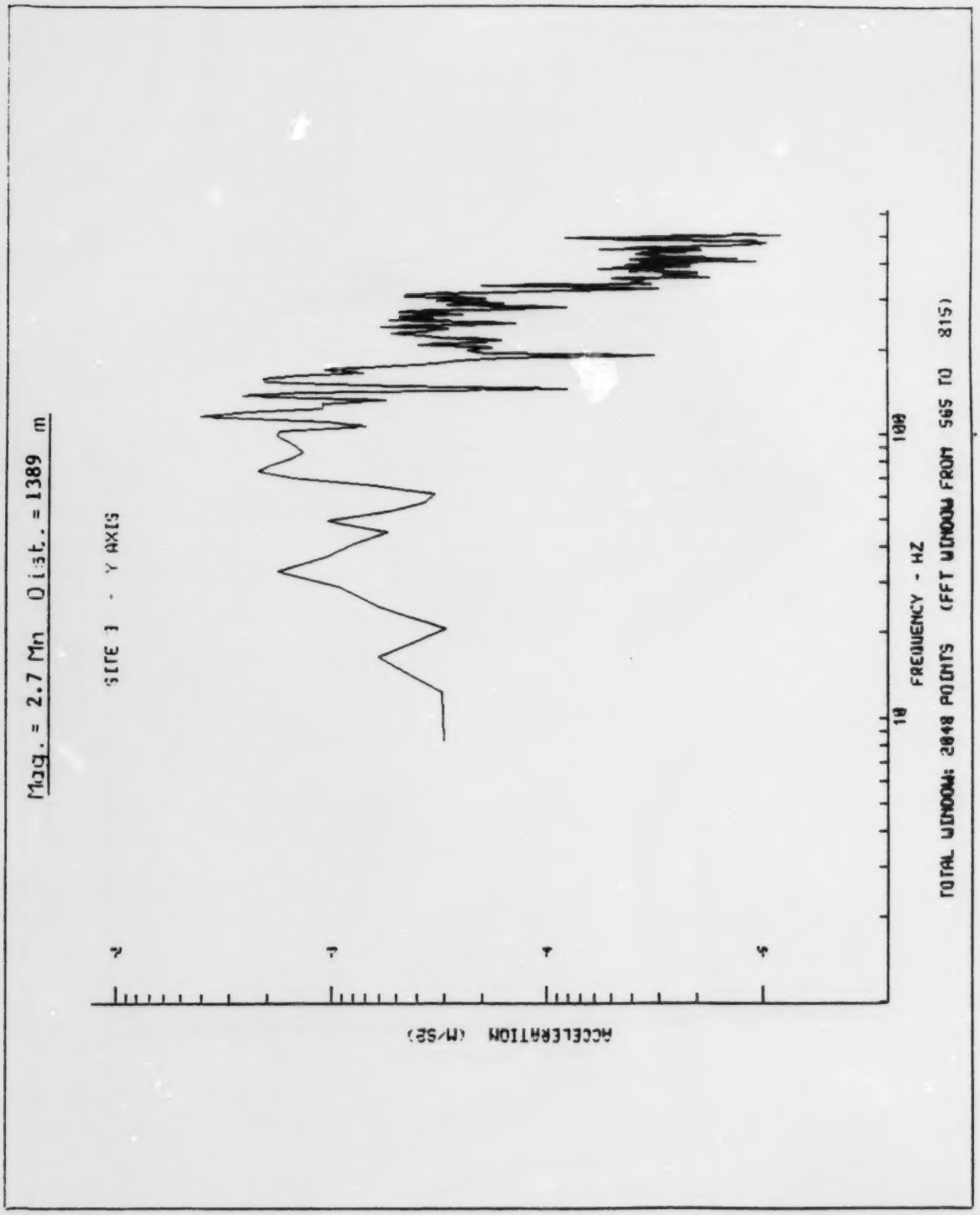

Fig. 4.26.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

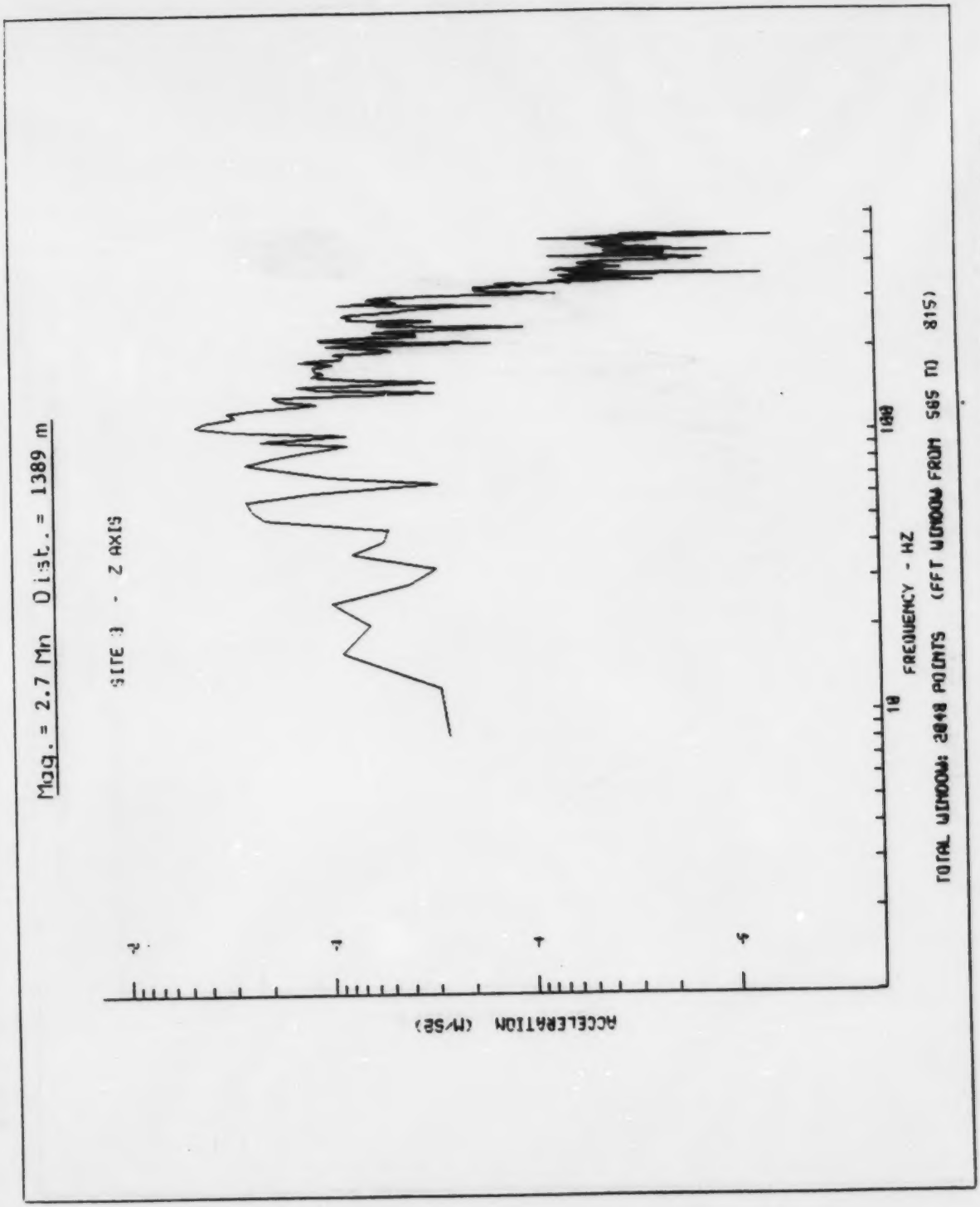

Fig. 4.26.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

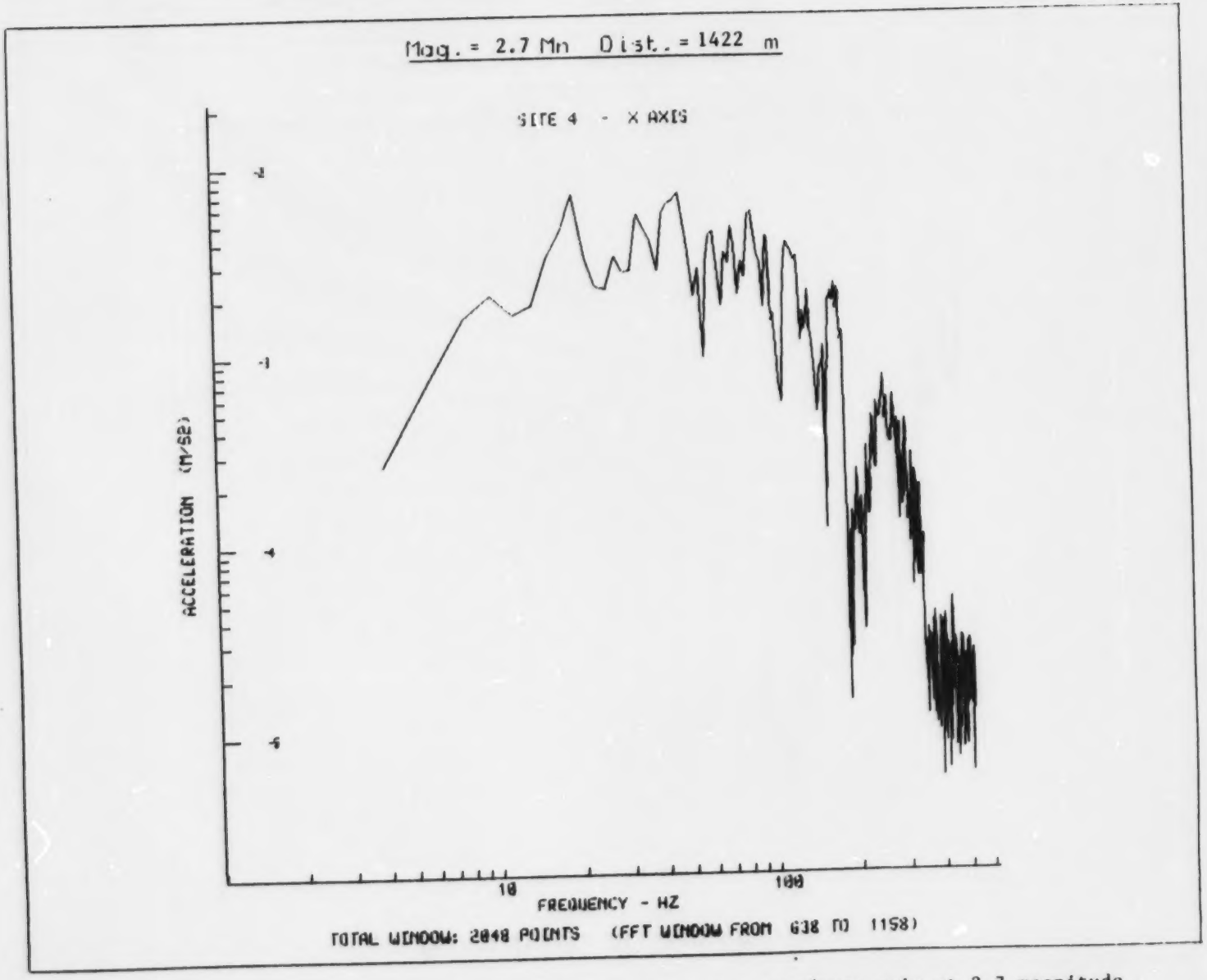

Fig. 4.27.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

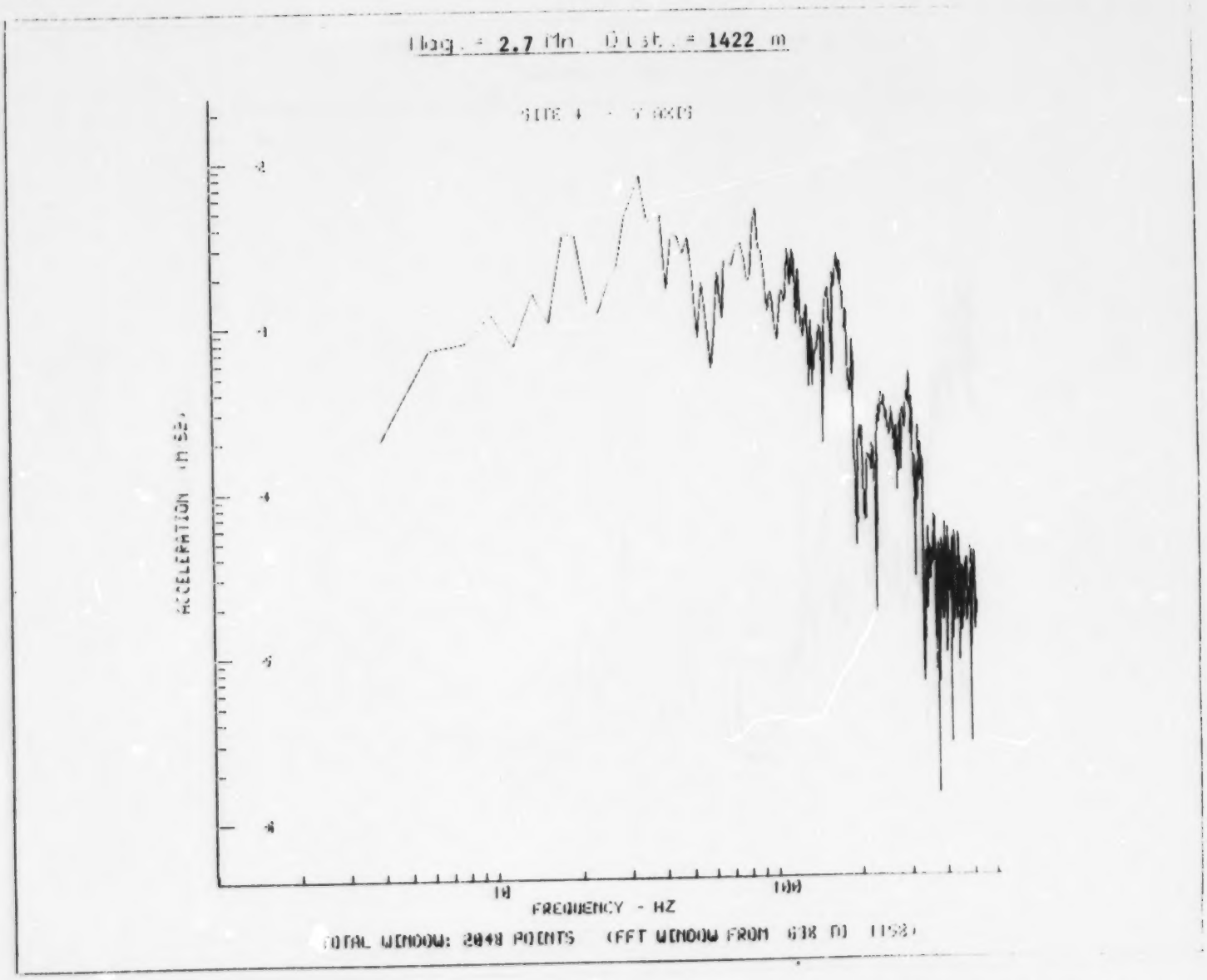

Fig. 4.27.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

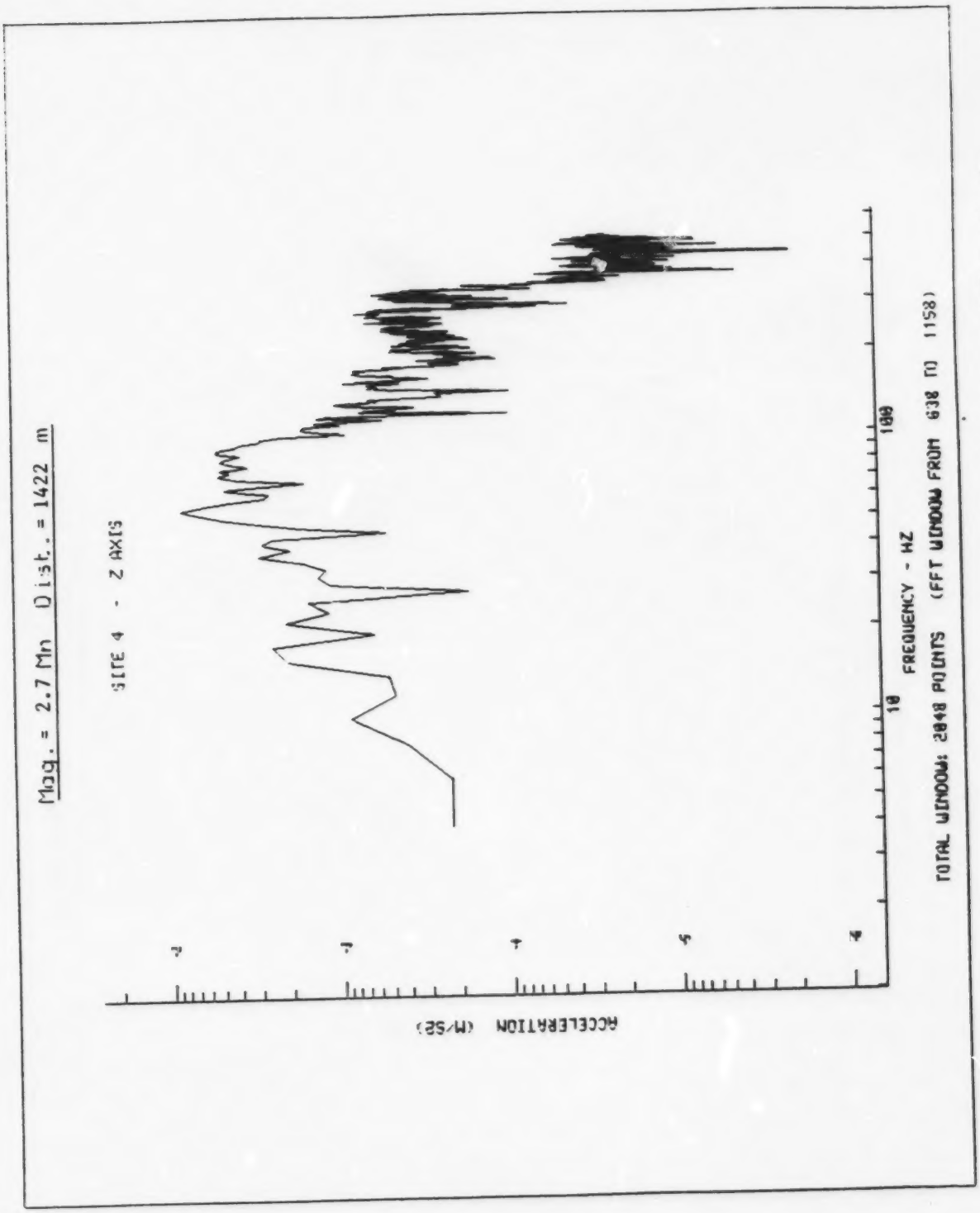

Fig. 4.27.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

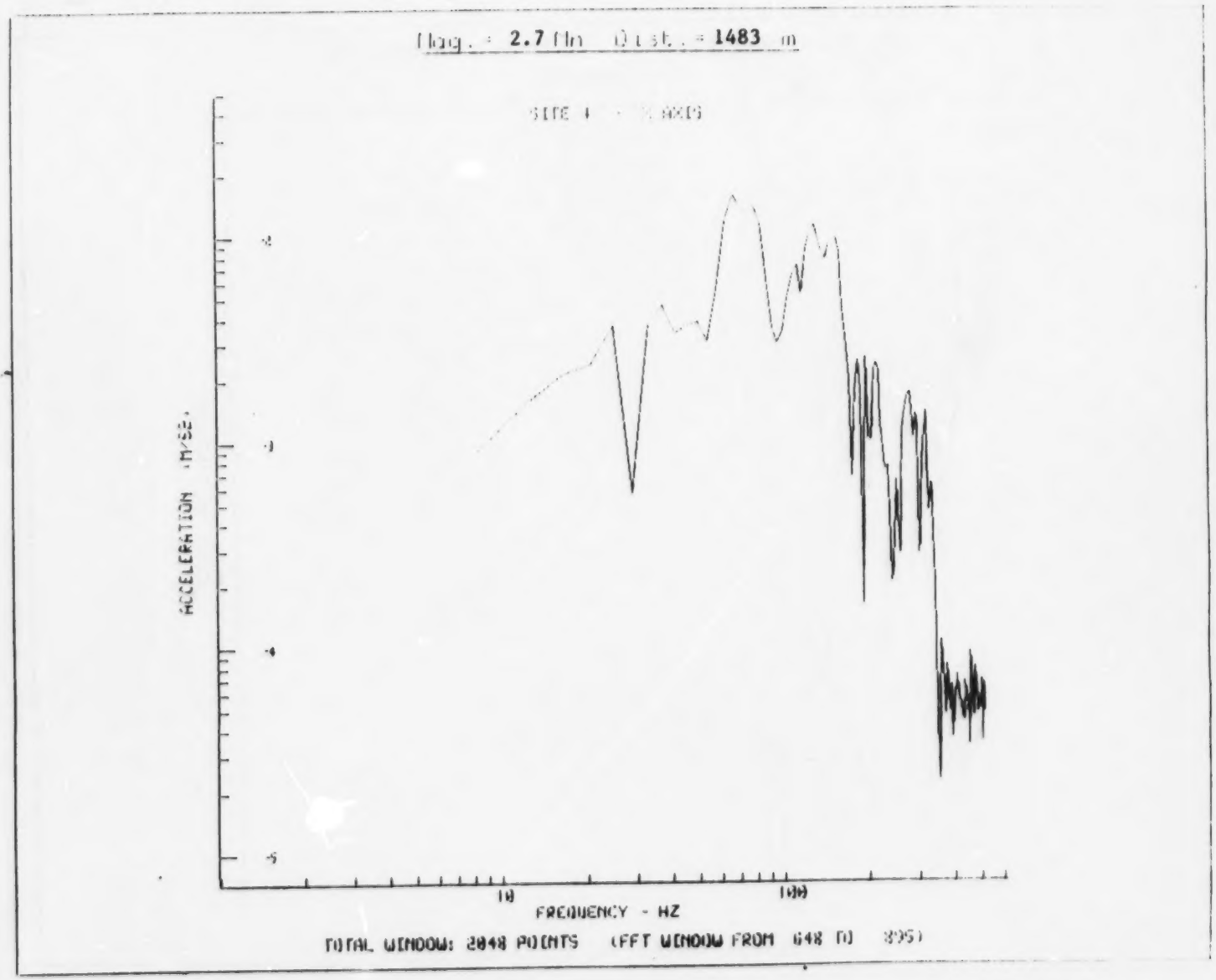

Fig. 4.28.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

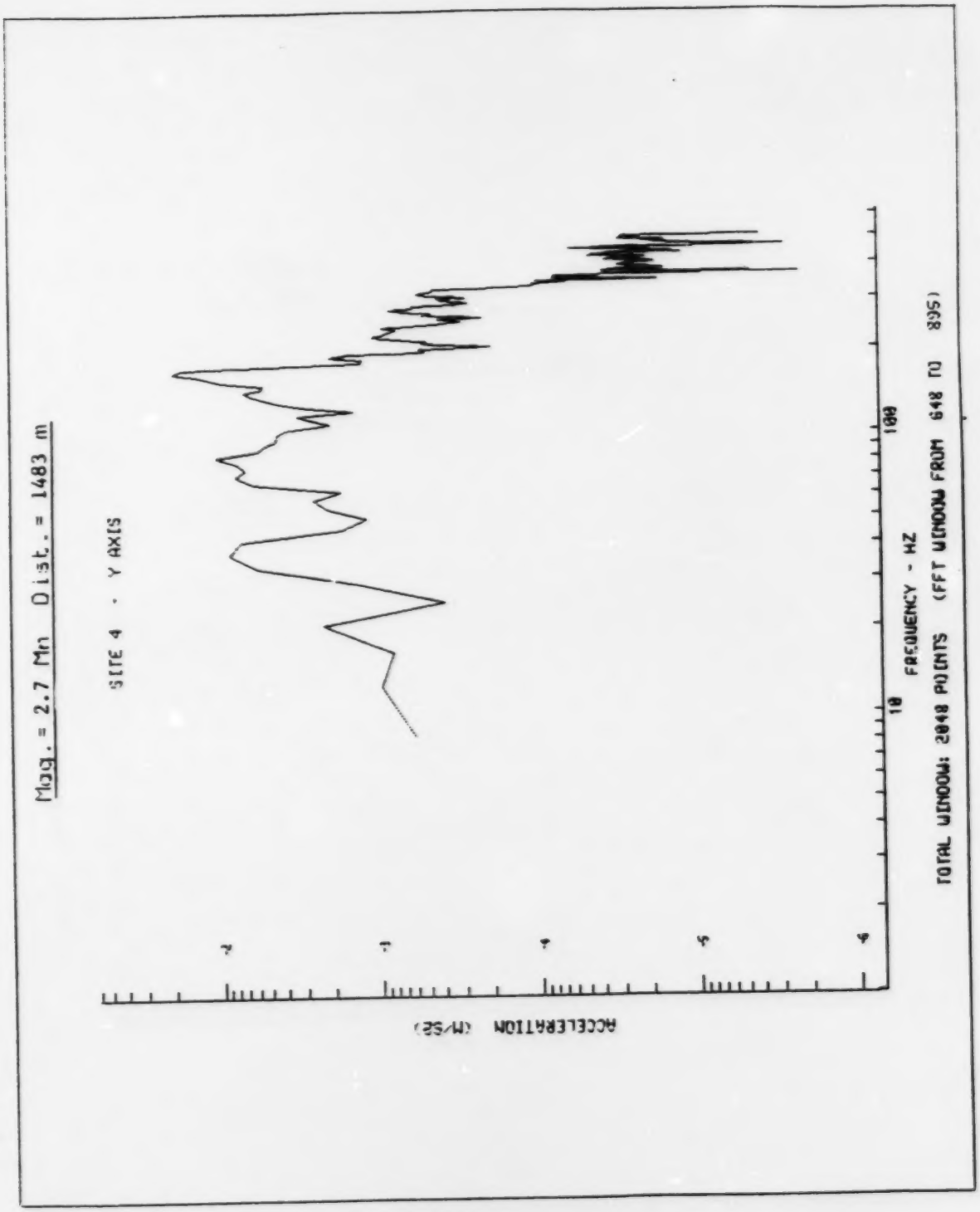

Fig. 4.28.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

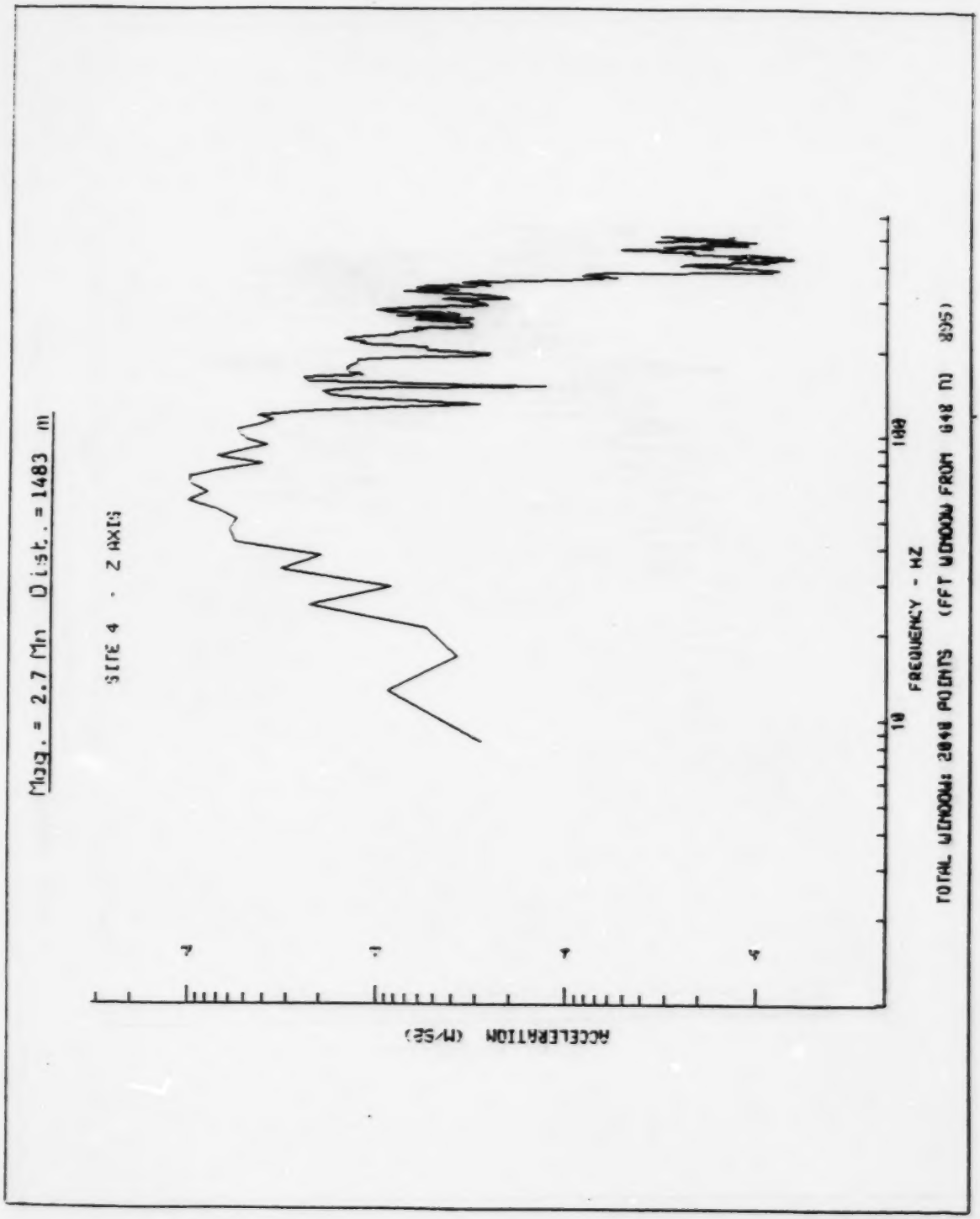

Fig. 4.28.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

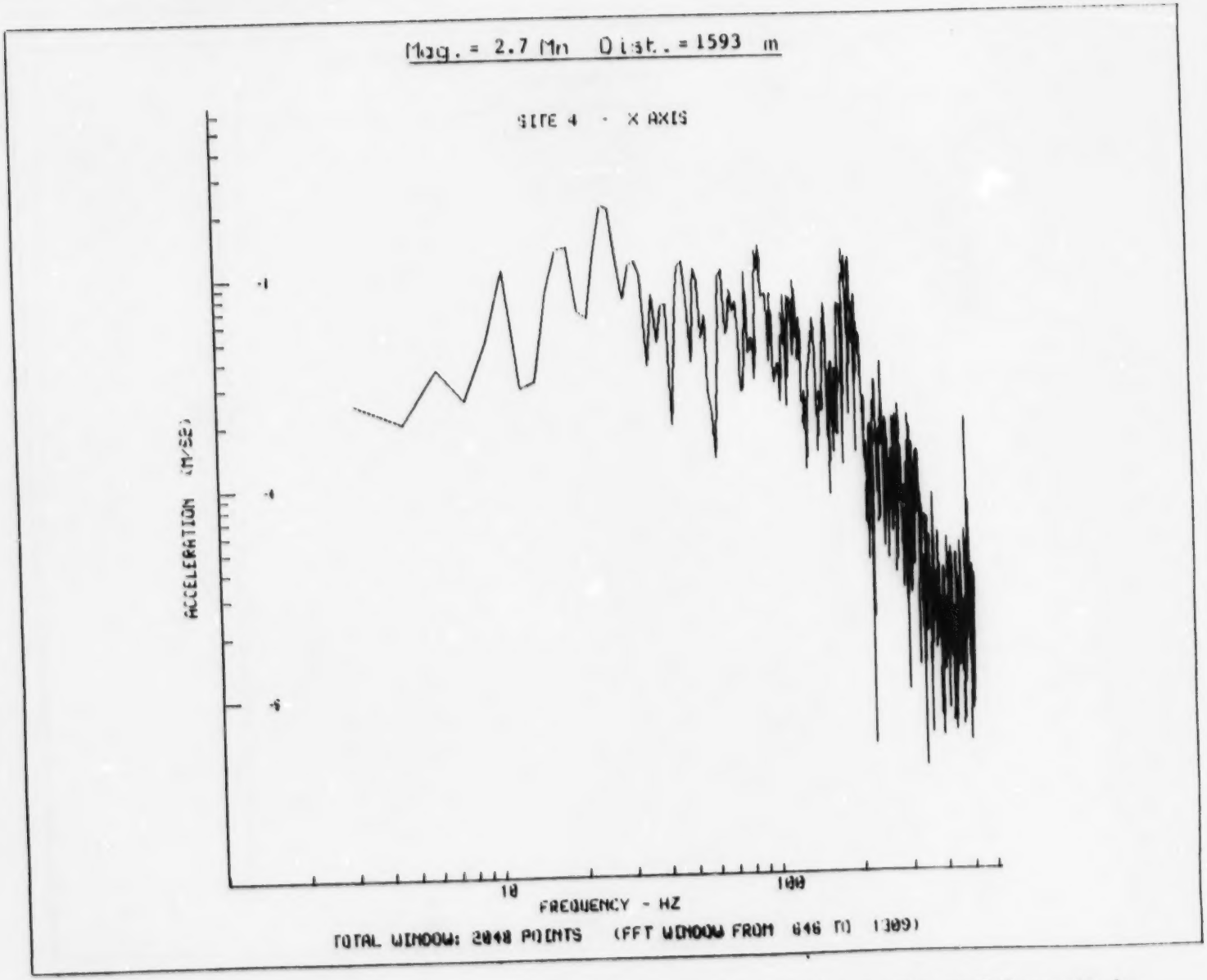

Fig. 4.29.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

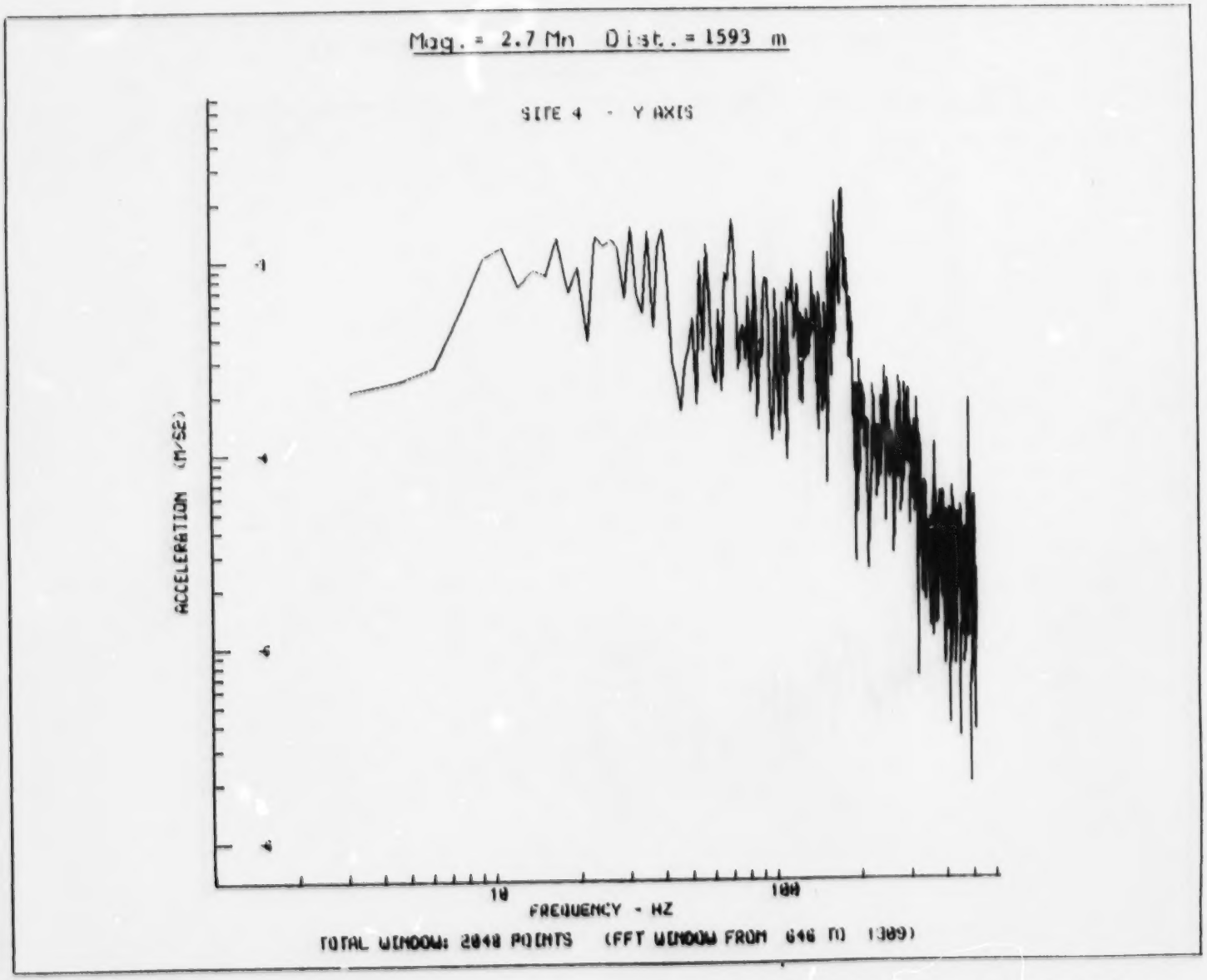
Mag. = 2.7 Mn Dist. = 1593 m
SITE 4 - Y AXIS
ACCELERATION (M/SE)
10
100
FREQUENCY - HZ
TOTAL WINDOW: 2048 POINTS (FFT WINDOW FROM 646 TO 1309)

Fig. 4.29.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

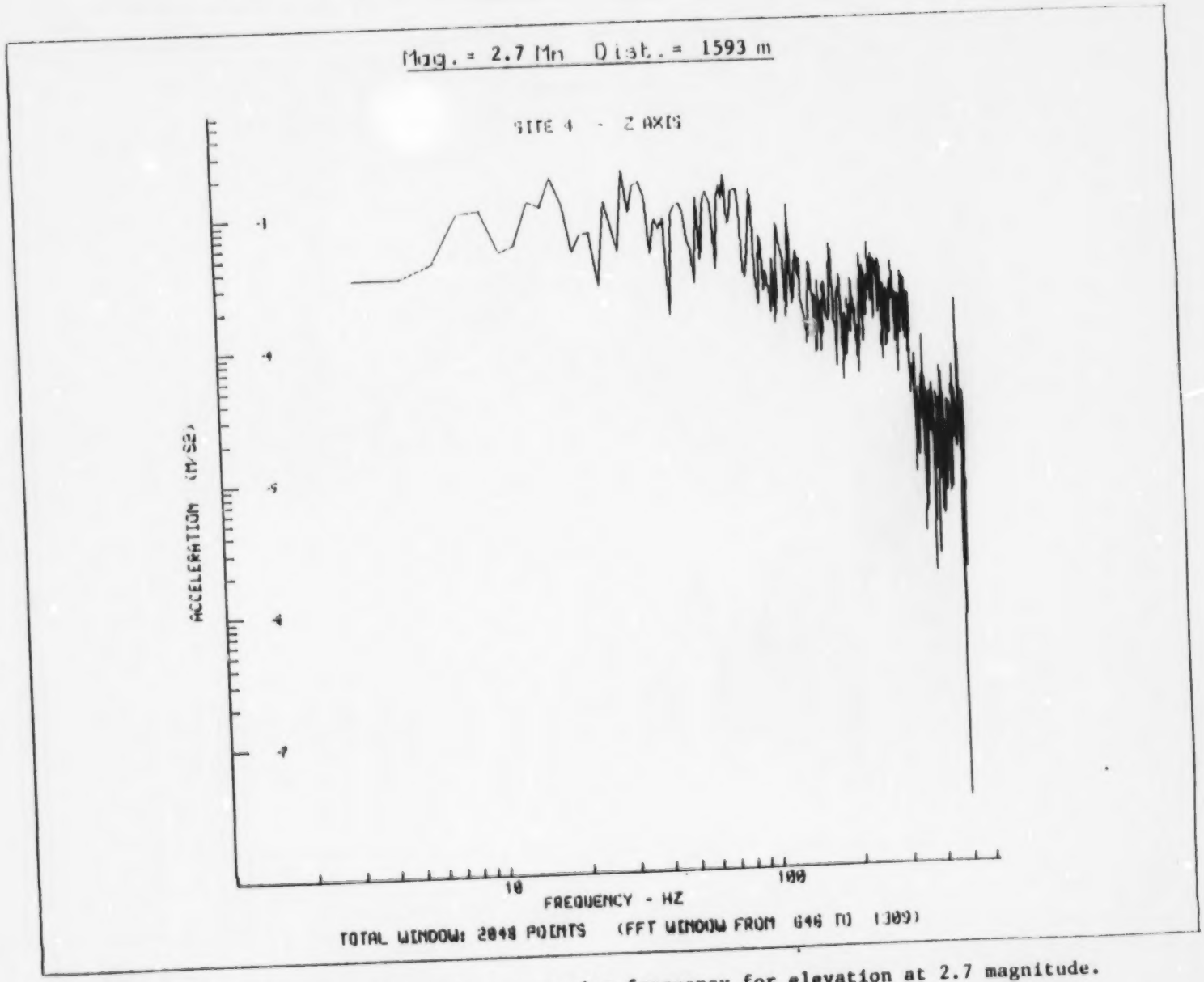

Fig. 4.29.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

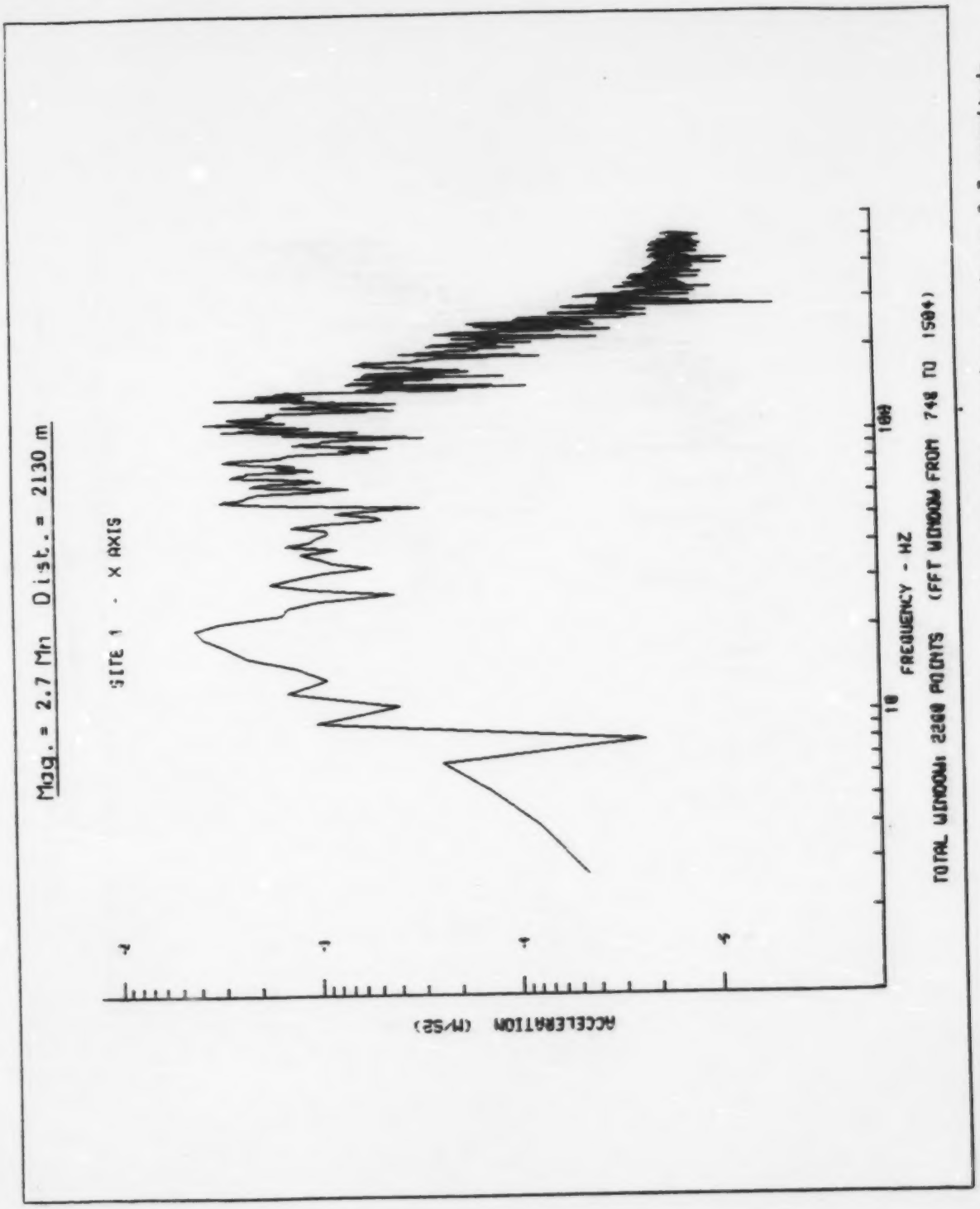

Fig. 4.30.1 - Log acceleration versus log frequency for east/west axis at 2.7 magnitude.

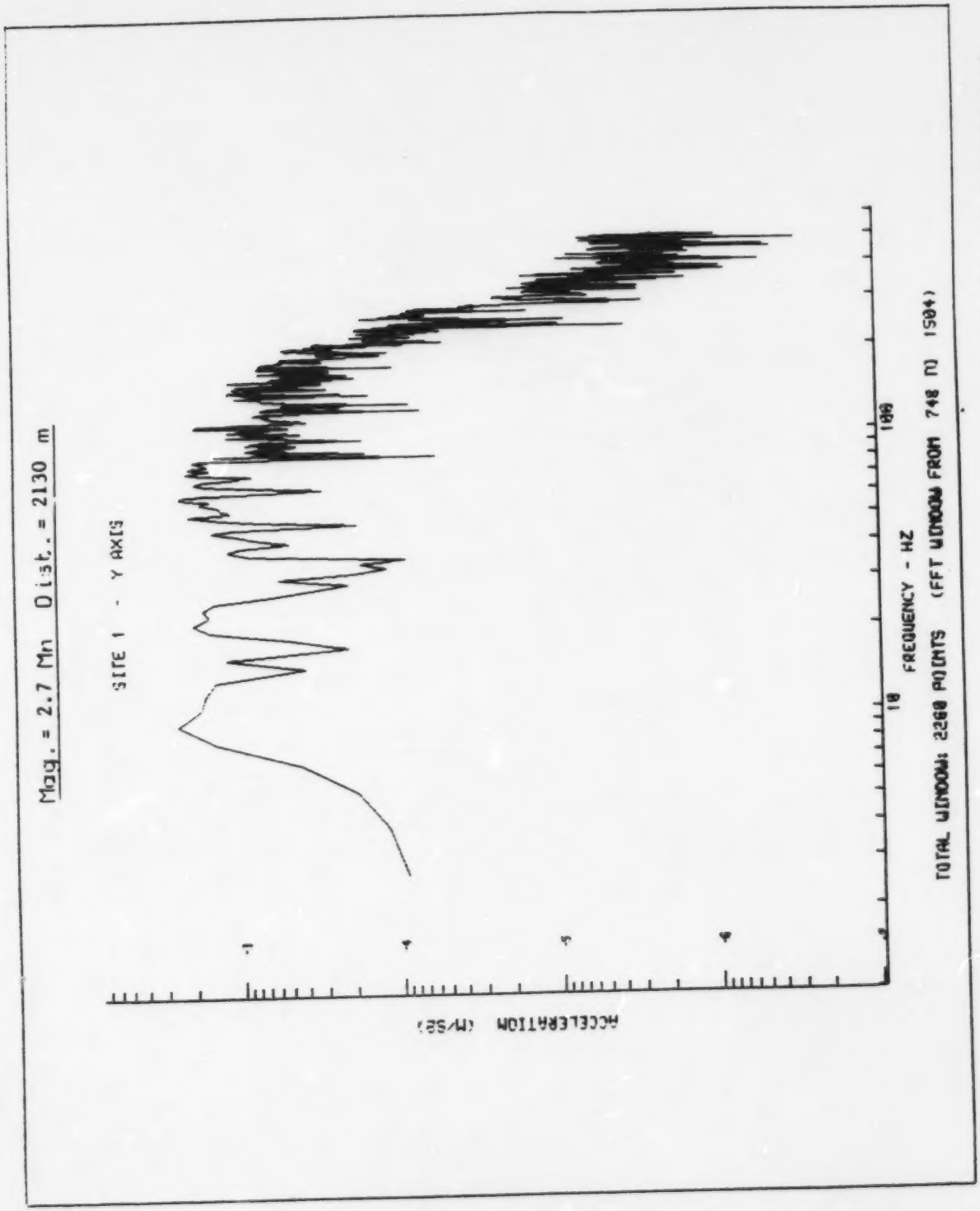

Fig. 4.30.2 - Log acceleration versus log frequency for north/south axis at 2.7 magnitude.

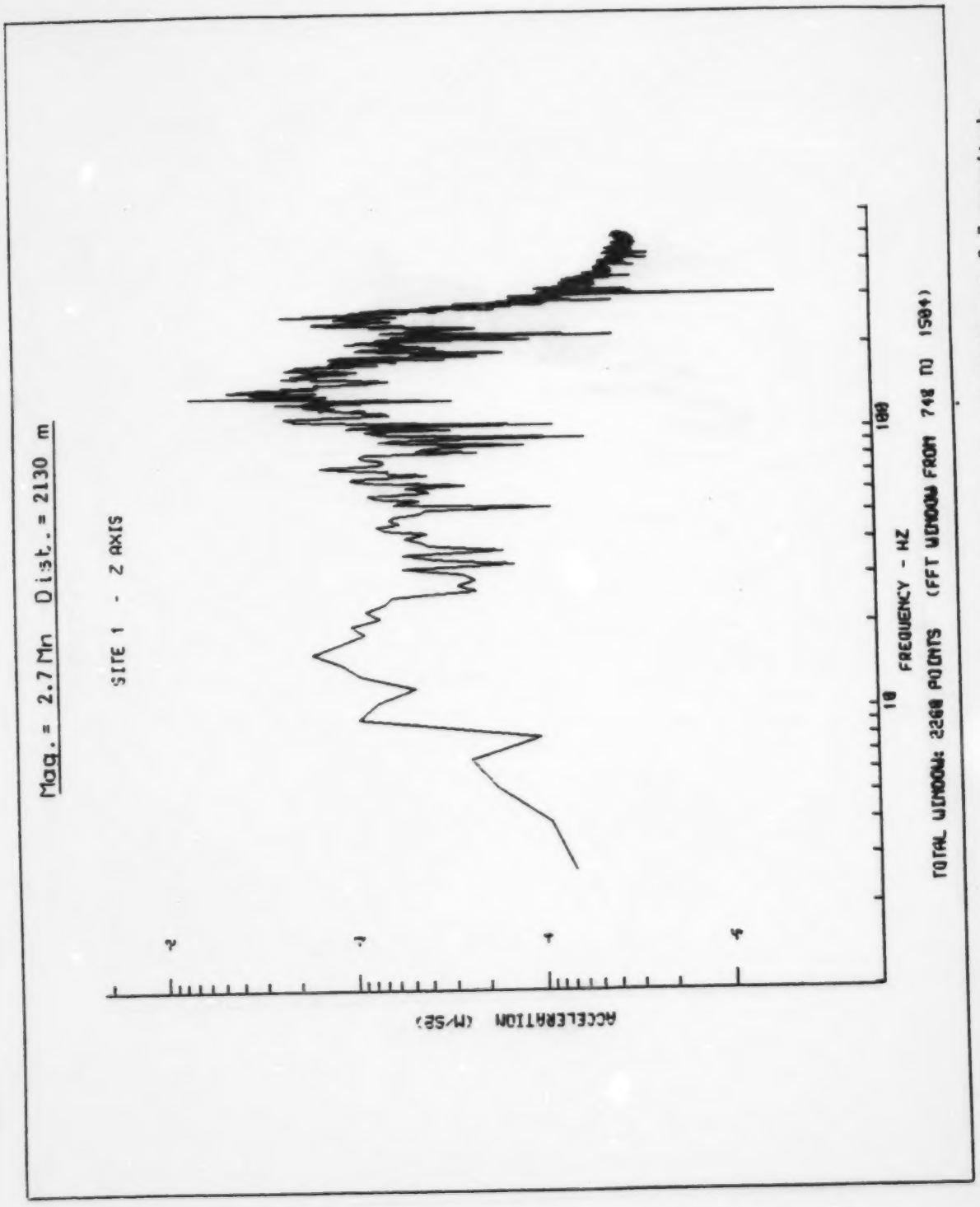

Fig. 4.30.3 - Log acceleration versus log frequency for elevation at 2.7 magnitude.

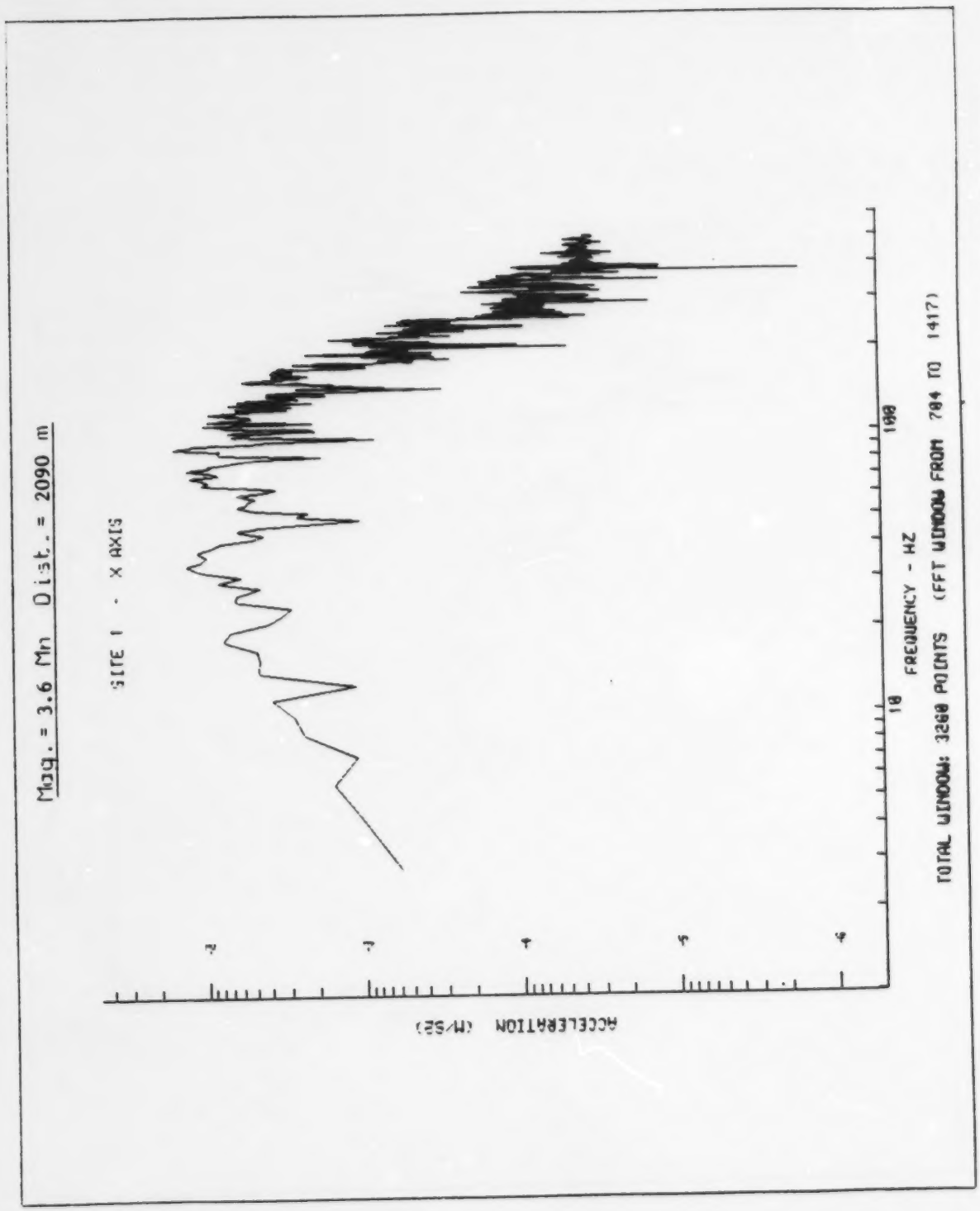

Fig. 5.1.1 - Log acceleration versus log frequency for east/west axis at 3.6 magnitude.

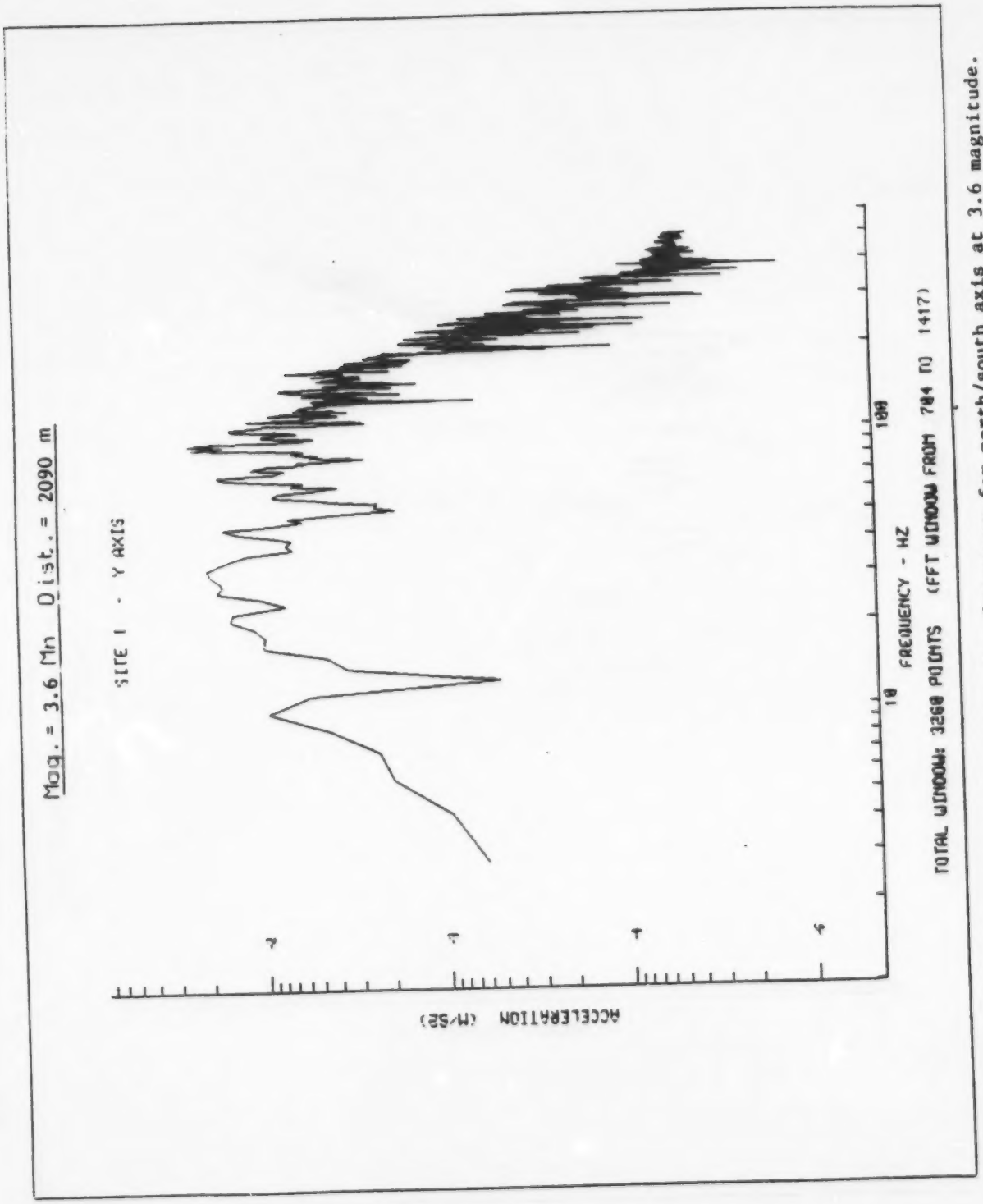

Fig. 5.1.2 - Log acceleration versus log frequency for north/south axis at 3.6 magnitude.

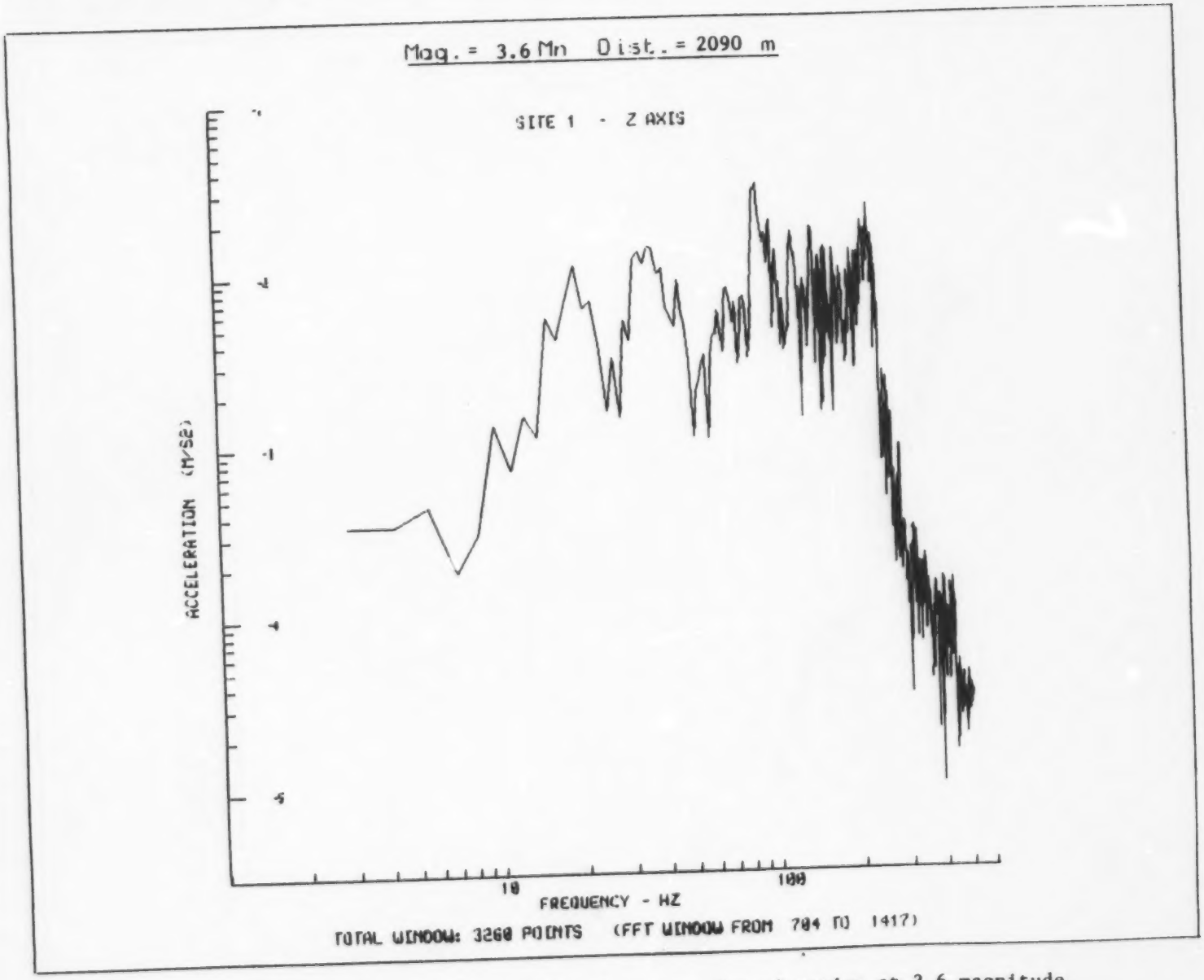

Fig. 5.1.3 - Log acceleration versus log frequency for elevation at 3.6 magnitude.

APPENDIX A

File Format on Diskette

fig 1.3
ACC log-log CHANNEL= 1

2.67363	5.89881E-05
4.01044	1.97690E-04
5.34726	9.66616E-05
6.68407	1.23326E-04
8.02089	6.50876E-05
9.35770	1.84153E-04
10.6945	1.84295E-04
12.0313	2.16022E-04
13.3681	3.67769E-04
14.7050	6.44979E-04
16.0418	3.48174E-04
17.3786	1.46061E-04
18.7154	2.27541E-04
20.0522	4.37477E-04
21.3890	6.27241E-04
22.7258	1.15679E-03
24.0627	4.14940E-04
25.3995	2.66066E-04
26.7363	7.16759E-04
28.0731	2.57322E-04
29.4099	4.50507E-04

ACC log-log CHANNEL= 2

2.67363	8.92295E-05
4.01044	1.81319E-04
5.34726	1.58299E-04
6.68407	1.12406E-04
8.02089	2.47924E-05
9.35770	2.01766E-04
10.6945	1.627[illegible]E-04
12.0313	3.007[illegible]E-04
13.3681	2.526[illegible]E-04
14.7050	2.26201E-04
16.0418	3.61732E-04
17.3786	1.93342E-04
18.7154	4.07265E-04
20.0522	4.99810E-04
21.3890	5.02163E-04
22.7258	2.19701E-04
24.0627	3.62281E-04
25.3995	7.83806E-04
26.7363	4.43222E-04
28.0731	3.45874E-04
29.4099	4.82457E-04

ACC log-log CHANNEL= 3

2.67363	2.80906E-04
4.01044	1.75175E-04

5.34726	2.42289E-05
6.68407	1.29284E-04
8.02089	2.89368E-04
9.35770	1.85964E-04
10.6945	2.20142E-04
12.0313	3.87659E-04
13.3681	1.04612E-03
14.7050	9.09555E-04
16.0418	5.59481E-04
17.3786	1.23723E-03
18.7154	1.48495E-03
20.0522	1.00321E-03
21.3890	1.09436E-03
22.7258	1.01069E-03
24.0627	9.35145E-04
25.3995	2.26123E-04
26.7363	1.59332E-04
28.0731	8.13660E-05
29.4099	1.47784E-04